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Great Lakes-Illinois River Basins Project

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INTRODUCTION

This report presents information obtained from biological studies in Lake Michigan between April 24, 1962 and December 4, 1962. Sampling stations were established at intervals of approximately ten miles throughout the lake; on 1, 4, 7 and 10 mile contours from the shoreline in the southern basin; and at intervals of two or three hundred yards in Milwaukee and Chicago harbors. The sampling stations on the one to ten mile contours are referred to as inshore stations in this report.

These biological studies were made for the purpose of: (1) evaluating the general biological condition of the lake, (2) defining areas adversely affected by wastes from tributary streams and sewer outfalls, and (3) supplementing and substantiating chemical, bacterial and physical data.

PARAMETERS: DEFINITIONS AND SIGNIFICANCE

Phytoplankton

The suspended microscopic plant life, called phytoplankton (or planktonic algae), are only slightly motile and exist at or near neutral buoyancy. As such they are subject to lake currents and represent the microflora of the sampling site only at the time of sampling. When growth factors such as pH, temperature and light are at optimum levels, phytoplankton uptake of nutrients is rapid. The presence of phytoplankton in certain kinds and numbers reflects the nutrient concentrations of water in the region from which it was collected. Most recent investigators agree that nitrogen and phosphorus are essential for algal growth, and that phosphorus is usually the limiting element since natural waters contain ample amounts of nitrogen but not phosphorus(1, 2). Bogan has demonstrated that algae reproduce prodigiously when phosphate phosphorus is added to water (1). Uptake continues as more phosphorus is added until dense concentrations of algae result, or until another growth factor is removed or depleted. Therefore, the charting of phytoplankton densities in a lake demonstrates localized and overall effects of nutrients, and provides valuable insight as to the biological productivity of the lake.

In addition, a determination of the kinds of planktonic algae that predominate permits appraisal of the effects of wastes on areas influenced by streams tributary to the lake. For example, some genera of algae such as Cyclotella, Stephanodiscus, and Melosira are common in midwestern streams (3), but Asterionella, Fragilaria, and Tabellaria are forms common to Lake Superior and Lake Michigan (3). Therefore, the zones of influence in the lake by the tributaries can be defined by plots of the kinds and numbers of planktonic algae.

Algae and Eutrophication

Historically, nutrient enrichment of lakes has increased biological productivity. This is known as eutrophication, or lake aging (4). Eutrophication is primarily manifested in increasing densities of planktonic algae. When nutrients for the growth of aquatic plants become available the planktonic algae develop. As the concentration of nutrients becomes greater the density of algal growth also may become greater. The algae, which are artificially grouped into grass green, blue-green, flagellates, and diatoms, are beneficial in moderate amounts and

only become troublesome when they become too numerous, and particularly troublesome if the blue-greens become predominant. An overabundance of planktonic algae results in a green murky water which sometimes produces unpleasant odors and unsightly scums. As the algae become more numerous, the transparency of the water decreases and sunlight is denied the rooted aquatic plants in the lake bottom. When the rooted plants are destroyed the breeding places for the animal life upon which the fish feed and the hiding places for juvenile fish are removed. Water filtration plants experience difficulty through tastes and odors and clogging of sand filters (5), and industrial water users must combat slime and corrosion.

The nutrients that support planktonic algae also promote the development of attached algae which cover all suitable substrata wherever sufficient light can penetrate. Lake Erie has exhibited luxuriant growths of an attached algal form called Cladophora for many years and more recently these algae have become a nuisance in certain areas of Lake Ontario (6) and Lake Michigan (7). They break loose as they mature, or during storms, and litter the beaches, foul fishing nets, and clog water intake screens. Whether the presence of extensive underwater meadows of Cladophora is an indication of eutrophication is not well defined but the fact that they exist in well fertilized waters has been established (6).

In the deeper areas of the eutrophic lake, more particularly below the thermocline, dissolved oxygen values may be drastically reduced due to the oxygen demand exerted by the decay of biological materials. The algae which become dense during the summer months die off and are succeeded the next year by another crop of algae. As the algae die, they settle to the lake bottom and are attacked by microorganisms that, along with the macro-animal forms in the bottom ooze, exert an oxygen demand. As the years progress and algae densities increase, the demand and subsequent diminution of oxygen below the thermocline increases accordingly.

Eutrophication may be either natural or induced. A lake undergoes natural eutrophication as the nutrients that support algal growth enter the lake with soil runoff. Algae, in their growth functions, use the mineral nutrients that have been leached from the soil. If the soil is fertile, nutrients for algae are likely to be abundant. During the warmer months algae populations tend to increase up to the point where one of the essential nutrients has been depleted. Since nitrogen and phosphorus are not abundant in young glacial lakes, those nutrients are rapidly removed, and the

algal blooms do not reach nuisance proportions. However, as nutrients are continually fed by leaching from the soils in the drainage area and the concentration of those nutrients rises, more planktonic algae develop.The eutrophic lake exhibits periodic algal blooms of proportions sufficient to cause the nuisance conditions discussed previously.

The eutrophication of a lake is accelerated by the addition of nutrients other than those from natural sources (4). Treated sewage contains high concentrations of the nutrients required for algal growth and has been responsible for induced eutrophication of many lakes throughout the world. Unfortunately, the most modern sewage treatment facility removes only part of the growth nutrients in sewage, and even treated sewage adds substantial quantities of nutrients to the receiving waters. The Zurichsee, a deep (16,500 acre) glacial lake in the Swiss Alps, is a classic, much-studied example of induced eutrophication through the introduction of domestic wastes (4). The lake is composed of two basins separated by a narrow passage. The upper basin received no sewage and remained essentially unchanged during the five decades that the lower basin received sewage from communities with a combined population of about 100,000. The basin receiving sewage changed from a clear-water lake to one murky with algae, and finally to advanced aging where the noxious blue-green algae predominated. The deep-water trout and whitefish vanished from this lake early in the process. This permitted the less desirable and more tolerant coarse fish to become dominant.

The Madison, Wisconsin lakes have had a similar history, as have numerous less-publicized ponds and small lakes throughout our country (2). Lake Erie has undergone considerable change in the past 25 years and recent investigations indicate that it is becoming an eutrophic lake (8).

Lake Michigan has been considered an oligotrophic lake, or one that is deep, clear, and contains little organic material; however, the recent Lake Michigan Short Filter Run Study, by Gamet and Rademacher, disclosed that the northern half of Lake Michigan yielded samples containing fewer algal cells than samples from the southern half where the major waste sources are located (5).

Long term records of plankton populations in Lake Michigan at Chicago indicate a gradual rise over the past fifty years (9).

Benthic Fauna

The kinds and numbers of benthic fauna inhabiting a particular lake area are determined by the characteristics of the substratum, the quality of the water, and certain physical features such as currents, wave action, temperature and light.

The habitats suitable for the predominant Lake Michigan organisms are as follows (10):

Organic sediment, turbid water:
- Oligochaeta (sludgeworms)
- Tendipedidae (midge larvae)
- Hirudinae (leeches)
- Pulmonata (air-breathing snails)

Sand and gravel, clear water:

- Amphipoda (scuds)
- Prosobranchia (gill-breathing snails)

The abundance or scarcity of a particular species in a given place is an indication of its ability to exist under periods of critical conditions (11). Examples of pollution-tolerant lake animals which fall into this category are the sludgeworms, bloodworms, leeches and air-breathing (pulmonate) snails. They are capable, by virtue of physiological features or living habits, of withstanding polluted conditions and their populations increase rapidly when competition with other forms is eliminated. Of these, the tubificids (sludgeworms) have been shown by Goodnight and Whitley to be particularly valuable biological indicators of organically enriched stream and lake bottoms. The Oligochaeta and Tendipedidae are known to exist in streams and lakes where oxygen levels are near depletion. They are also considered more tolerant of other pollutants. As lake conditions develop for these tolerant organisms, the more sensitive animals are reduced in numbers.

One genus of the Amphipoda, Pontoporeia, was found in biological collections from all areas of Lake Michigan, and was the predominant bottom-dwelling organism in areas not greatly influenced by organic sediments. The relative scarcities of Pontoporeia and concomitant abundance of Oligochaetes are, therefore, considered reasonable indicators of lake areas subjected to organic enrichment if other conditions are favorable to its growth.

The use of bottom-dwelling animals to evaluate lake aging is questioned, because they reflect the water quality only at the mud-water interface and not necessarily at other levels. A condition of progressive biological productivity is indicated, however, in areas where there is an abundance of bloodworms, sludgeworms, and leeches.

Organic Matter

The organic matter in lake water is either dissolved or particulate. This determination deals with the particulate organic matter which consists of phytoplankton (minute plants), zooplankton (minute animals), and non-living organic matter. The bacteria and smallest algae, and the fishes are not included.

The amount of organic matter per cubic meter of water is a gross measure of the biological productivity potential, and when considered with phytoplankton densities supplies substantial information as to the actual productivity. Generally, values less than 100 milligrams of organic matter per cubic meter of water are indicative of low biological productivity, and values higher than 100 mg/m^3 are obtained from highly productive waters (12). In 1959 a series of vertical plankton tows in the middle of Lake Ontario yielded values ranging from 8 to 80 (13).

High concentrations of organic matter in harbor areas would not necessarily indicate high biological productivity. A study of phytoplankton densities might reveal low values, in which case the organic materials would be suspected as being from sewage or industrial wastes. Therefore, in interpretation of the data, any known sources of organic wastes which influence the lake area must be considered. Chemical data from samples taken concurrently should supplement the biological information.

Light Penetration

Water transparency from the lake surface to a given depth is directly related to transmission of light energy and the consequent production of biological materials (12). If all other growth factors are present, optimum light remains as the limiting growth factor. While the method for determining transparency has inherent faults due to surface ripple, surface reflection, and variations among humans in ability to see, the fact remains that the light that penetrates to a submerged object is a light source for photosynthetic plants.

Measurement of transparency has long been used by limnologists and the value of these data is therefore enhanced by correlations of transparencies and other pertinent data, such as phytoplankton and nutrient densities, in one situation with the same data revealed in another situation. For example, Rawson (14) in his studies of six oligotrophic lakes and six eutrophic lakes in Canada found that transparencies less than ten feet occurred under algal bloom conditions in the eutrophic lakes. He also indicated that transparencies of 20 feet or more were common in the oligotrophic lakes. Investigators at Lake Washington, Seattle also reported that transparencies of the lake water decreased as phytoplankton densities increased (15).

Colloidal and suspended matter emanating from the shores produce high turbidities and reduce the transparency of the water. This in turn results in a reduced phytoplankton density. Therefore, low values for transparency are meaningless unless phytoplankton populations are determined for the same waters at the same time. Where suspended solids effect low transparencies the impact due to the reduction in productivity is secondary to the possible damage to the general lake biology after sedimentation and conversion of some of the materials to available nutrients.

METHODS AND PROCEDURES

All samples of biological materials were collected by biologists working cooperatively with other Project scientific personnel. Samples were taken at the same times and places as the samples taken for chemical, bacterial, and physical analyses. The methods and equipment were those described in either "Standard Methods for the Examination of Water and Wastewater," 11th Edition (16), or "Limnological Methods," Welch, 1948 (17).

Laboratory methods also followed those prescribed in the above publications.

1. Phytoplankton samples were preserved in the field by adding enough formalin to effect a 3% solution in the water sample. One milliliter of the sample in a Sedgwick-Rafter counting cell was examined microscopically in such a way that one-twentieth or one-tenth of the cell was observed. The microscope was fitted with 10X oculars and a 20X objective for counting, and 43X and 97X objectives for identification of the organisms. Each one-celled alga, filament, and colony was counted as one organism. Results were tabulated as numbers of individual organisms per milliliter of sample.

2. Bottom-dwelling animals which had been dredged from the lake bottom and preserved with formalin were washed in the laboratory, preserved with alcohol, sorted by families, identified, and counted. Results at each sampling station were recorded as numbers of organisms per square meter of lake bottom.

3. Organic matter at each sampling station was determined by lowering a standard limnological 0.5 meter plankton net to the lake bottom and raising it to the surface. All of the material large enough to be retained was washed into containers, preserved with formalin, and returned to the laboratory. In the laboratory the dry weight at 105°C and the ashed weight at 600°C were determined. The loss due to ignition represented the organic matter (except the smallest plankters called nannoplankton) in a column of water 0.5 meter in diameter from 1.5 meters off the bottom to the surface. The data are reported as milligrams of organic matter per cubic meter (mg/m^3) of water.

4. Light penetration of the water at each sampling station was determined by an eight inch diameter disc having alternating white and black quadrants. The disc was lowered in the water by a graduated line until it disappeared, raised until it reappeared, and the average of those two depths recorded. Measurements are reported in meters and tenths of meters. When a rough sea made visibility or reasonably accurate marking of the line difficult, no measurements were recorded.

RESULTS

To facilitate analysis the data are tabulated by lake sections as follows:

Southeast Quadrant	South and east of Lat. 43°30' Long. 87°00'
Southwest Quadrant	South and west of Lat. 43°30' Long. 87°00'
Northern Basin (except Green Bay)	North of Lat. 43°30'
Green Bay	
Milwaukee Harbor	
Chicago Harbor	

The data are summarized by showing the frequency at which ranges of values occurred at Sampling Stations 1, 4, 7, 10, and beyond 10 miles from shore. No allowance has been made for seasonal differences in the tables, but the phytoplankton densities are presented graphically by lake cruises in chronological order. Two cruises in October and November coincided. The data obtained during those months are shown in Figure 7.

Intensive sampling was carried out in the southern basin and at widely separated stations in the northern basin. Therefore the results presented and the conclusions that follow will necessarily specify conditions that exist in the southern basin and generalize on the biota of the northern basin. Each of the parameters will be discussed separately.

Phytoplankton

Favorable conditions of light, temperature, and turbulence produce amounts of phytoplankton that increase with the added availability of nutrients. Many inorganic elements are required for plant growth, including: silica, calcium, potassium, phosphorus, and nitrogen. Organic substances are probably required also, but the present lack of knowledge precludes identification of the compounds. Natural waters usually contain ample quantities of all of the known nutrient materials except phosphorus and nitrogen. Therefore, phosphorus and nitrogen are considered the principal limiting factors in algal growth, and high phytoplankton densities reflect high phosphorus and nitrogen concentrations.

The averages for nitrate nitrogen and total phosphate, as determined by the Great Lakes-Illinois River Basins Project (and reported in Special Report LM-3, "Chemical and Physical Investigations") were 0.12 mg/l and 0.01 mg/l, respectively; inshore concentrations as high as 0.36 mg/l and 0.27 mg/l, respectively, were found.

Stations near the shoreline yielded samples containing concentrations of nitrogen and phosphate high enough to produce large populations of algae. Samples from stations in the middle of the lake were generally deficient in the amounts of nitrogen and phosphate required for production of algae in bloom proportions.

The densities of phytoplankton generally followed the same pattern as nutrient concentrations. Total counts of phytoplankton (Figures 1 through 7) ranged from 2,500-5,000 per ml at many of the stations one, four, seven and 10 miles from shore with slightly higher counts along the eastern shore. Beyond 10 miles from shore the densities of phytoplankton diminished greatly. Counts in this middle area of the lake were rarely more than 500 per ml. Tables 1 and 2 present phytoplankton data by the number of stations at which ranges of values occurred. Ranges of phytoplankton densities in counts per ml for sampling periods between April and November are as follows:

Sampling Period	Inshore - 1-10 miles	Beyond 10 miles
April 24 - May 7	198 - 4,788	165 - 900
June 5 - June 18	352 - 1,067	98 - 440
July 17 - July 30	33 - 1,428	28 - 385
August 29 - September 9	33 - 1,034	No Samples
October 9 - October 23	42 - 2,086	No Samples
October 18 - November 30	88 - 6,182	No Samples
October 28 - December 4	44 - 1,474	44 - 264

Although total counts of phytoplankton in the 1,000-5,000 per ml ranges indicate relatively high biological productivity, the kinds of algae present are equally important. The diatoms Melosira and Cyclotella, which are common inhabitants of nutrient-enriched waters were the genera that predominated samples from Milwaukee Harbor and most of the shoreline stations from Milwaukee to Chicago (Table 2). Along the Michigan shoreline, Cyclotella predominated and Melosira were numerous in many samples.

In samples from stations beyond 10 miles, the diatoms Asterionella, Tabellaria, Fragilaria and Synedra were the predominant genera. (Table 2) These are the forms that have typified the planktonic algae of Lake Michigan for many years (9). They are also typical of Lake Superior and other oligotrophic lakes, where they completely dominate the phytoplankton populations. In true oligotrophic lakes, however, their numbers are less than those

observed in many Lake Michigan samples (14). It is also significant that Cyclotella sometimes occurred abundantly in mid-lake samples dominated by Asterionella, Fragilaria, Tabellaria and Synedra. Table 2 shows that averages of Cyclotella were relatively high in all sampling zones.

Benthic Fauna

Only eight different kinds of organisms occurred in consequential abundance, and the amphipods (or aquatic scuds), were abundant in all areas of the lake where conditions were favorable. They are the forms that prefer a habitat of sand or gravel and are not numerous in lake bottoms covered by organic sediments. The common genus of Lake Michigan amphipods is Pontoporeia. Their occurrence is summarized in Table 3 as percentages of amphipods to the total number of all benthic fauna, and the distribution of benthic fauna are shown graphically in Figures 8 and 9.

Table 3 shows that the southeast quadrant, one-mile stations were sparsely populated by scuds. However, nine of the 12 stations in the 0-25% occurrence range shown in the table represent one-mile stations running from South Haven to Michigan City. The lake bottom at these stations is subject to wave-induced shifting sands that provide a poor habitat for bottom-dwelling organisms and may be the reason for their scarcity.

Table 3 also indicates a paucity of scuds in Milwaukee Harbor and Green Bay, and significantly low populations in the deeper areas of the southwest quadrant.

The Oligochaeta (or sludgeworms) are another group of organisms useful in evaluating the effect of organic influents on the biota of the lake. These small worms prefer a habitat containing appreciable organic material. Table 4 summarizes the occurrence of this group of organisms by percentage of organisms to the total number of bottom-dwelling animals.

The effect of wastes in Milwaukee Harbor is clearly indicated by the number of stations where the sludgeworms constituted 75-100% of the bottom animal populations (Table 5). More noteworthy is the evidence of large populations of these organisms at the deepwater stations in both the southern and northern basins. Numbers of oligochaetes ran as high as 1,816 per m^2 of lake bottom at deepwater stations in the northern basin and 2,831 per m^2 in the southern basin.

Eighteen one mile stations are listed in the 0-25 per cent range of Table 4. Nine of those stations were in the area where wave action apparently inhibited amphipods.

The very tolerant midge larvae were not predominant at any of the stations but they were found at about two-thirds of the sampling stations. In some instances they were second to the sludgeworms in abundance and were otherwise the third most numerous organisms found.

An earlier study of the benthic fauna of Lake Michigan was made in 1952 and 1956 by Eggleton (18), (19). The results of that study and others in Lake Huron (20) and two Canadian lakes(14) provide information that reveals the changing character of Lake Michigan fauna. The Canadian lakes are included in the comparisons because one (Lake Athabasca) is a very oligotrophic lake and the other (Churchill Lake) is eutrophic. Both are in a remote area where effects due to human habitation have been negligible.

A comparison of percentages of the numbers of amphipods and oligochaetes reveal some interesting trophic features of these lakes, but more important are the comparisons of the fauna of Lake Michigan in 1931 and 1962. The percentages of organisms, the average number of organisms, and the highest number found in each lake are shown below.

Lake	Year	% Amphipoda	% Oligochaeta	% Other	Ave. No/m^2	Max. No/m^2
Churchill	1957	23	9	68	1,076	-
Athabasca	1947	61	12	27	1,275	-
Huron	1952 and 1956	77	9	14	1,461	10,556
Michigan	1931	65	24	11	1,243	10,200
Michigan	1962	48	39	13	4,229	26,257

(Harbor stations not included)

The 68% Other in Churchill Lake and 13% Other in Lake Michigan 1962 were mostly midge larvae (Tendipedidae) which are many times larger than amphipods and oligochaetes. The 1931 Lake Michigan study reports that fingernail clams were third in dominance. The change in species dominance and the increased populations of organisms are probably due to a change in habitat caused by organic sedimentation.

Organic matter

The organic matter in a half-meter-diameter column of water at each sampling station is summarized in Table 3. Results are given as milligrams of organic matter per cubic meter of water(mg/m^3).

In both the southeast and southwest quadrants the pattern of concentrations follows very closely those for phytoplankton counts where generally the plankton was at its highest density near the shoreline and diminished at stations further from shore. In the 0-25 mg/m^3 range of Table 3, proportionately more occurrences are recorded for the southeast quadrant where 37 of 57 were in that range. In the southwest quadrant 24 out of 111 plankton tows were within the 0-25 mg/m^3 range, and values range from 26-200 mg/m^3 at 87 stations. The Milwaukee Harbor stations had fewer low concentrations than the lake stations, due to a combination of organic wastes and high concentrations of phytoplankton. All of the values for organic matter were in the high ranges in Chicago Harbor. Since phytoplankton counts were low, the large amount of organic matter was either due to zooplankton or organic matter.

The northern basin was not sampled extensively but results from 9 of the 10 stations indicated low concentrations of organic matter. Only one was in the 76-100 mg/m^3 range which is indicative of moderately high productivity.

Light Penetration

The ranges of values shown in Table 8 were selected to determine the number of stations where light penetrations were higher or lower than six meters. This is the depth at which lesser values for light penetration indicate increased biological productivity; higher values indicate very clear water and low productivity. Values higher than 12 meters were observed at three stations in the southern basin and three stations in the northern basin. The deepest light penetration was 18 meters found at one station centrally located in the northern basin. The lowest values were less than one meter in Milwaukee Harbor. There was considerable difference in light penetrations at the inshore and mid-lake sampling areas. This is clearly indicated by the large number of inshore stations where values were less than 6 meters (Table 8). Penetration less than 2 meters was observed at 21 stations in the southwest quadrant. Most of those low readings were at stations on the one-mile contour along the Wisconsin and Indiana shores. Phytoplankton samples

taken at the same time produced high counts along the Wisconsin shore and low counts along the Indiana shore. Apparently, waste discharges in the Indiana area were responsible for high turbidities and resultant low biological activity.

CHICAGO BEACH ALGAE PROBLEM

The Chicago Park District has reported cases of beaches being fouled with algae washed in from the lake for many years. On Aug. 27, 1961 and on Aug. 16, 1962, Great Lakes-Illinois River Basins Project biologists investigated occurrences at Oak St. and Montrose beaches. In 1961 the offending organism was found to be Dichotomo siphon, a green filamentous alga similar in appearance to Cladophora. Rhizoclonium and Cladophora were also present. In 1962 Cladophora was the principal alga but Oedogonium was also present intermixed with the Cladophora. All of these organisms have similar growth requirements and all require a hard substratum, or attachment surface. The windrows of algae that completely lined the beaches became foul-smelling after a few days exposure to the summer heat. Flies and other insects covered the decaying masses.

Project biologists also examined filamentous algal growths on boats, breakwaters, buoys, and in harbors from Burns Ditch, Indiana to Green Bay, Wisconsin. They found that practically any submerged solid provides a surface for the growth of algae. Since the nutritional requirements of the filamentous algae are similar to the other algae it is concluded that concentrations of phosphorus, nitrogen, and other nutrients are ample in the shoreline areas of the lake between the southern tip of the lake and Green Bay.

CONCLUSIONS

Local Effects of Waste Discharges

The effects of wastes discharged at Milwaukee afford an excellent opportunity to evaluate the impact on the lake biota in a selected area. Both the phytoplankton data and benthic fauna data were typified by organisms favoring organic enrichment. The benthic fauna consisted of sludgeworms, and cleanwater types did not exist. Milwaukee Harbor is considered biologically degraded.

The dominance of Melosira and Cyclotella in the Milwaukee area was due to high concentrations of nutrients. The subsequent persistence of these organisms at many of the one and four mile stations south from Milwaukee to near Chicago is attributed to one or a combination of the following: (1) a lack of mixing with Lake Michigan waters, (2) a transport of nutrients coincidental with the organisms, (3) the addition of nutrients and organisms by waters emanating from Racine, Kenosha, and Waukegan harbors and waste outfalls.

It is likely that the phytoplankton density along the southwest shore would be greater if it were not for the extensive Cladophora meadows in the Milwaukee area, which take up nutrients and thereby reduce the nutrient availability for the phytoplankton. This is also a partial explanation for the slightly higher densities of phytoplankton along the Michigan shoreline. The rocky substratum that lies along the Wisconsin shoreline is not present on the Michigan shore so Cladophora has no attachment surfaces. However, the greater density on the Michigan shore is probably due to a combination of the lack of substrata and the prevailing westerly winds that cause the water to be warmer on the Michigan side of the lake. Higher water temperatures accelerate algal growth. The prevailing westerly wind would also hold the plankton-laden water against the eastern shore. In addition, the counterclockwise movement of water in the southern basin (as is suggested by tracing Melosira and Cyclotella from Milwaukee to Chicago) would transport nutrients to the Michigan shoreline.

General Biological Condition of Lake Michigan

The center of Lake Michigan did not yield abnormally high concentrations of phytoplankton or organic matter and light penetration was deep. The quality of the water in this mid-lake area was good. Biological activity was low and the flora (predominated by Synedra, Asterionella and Tabellaria) was similar to the flora of Lake Superior (3). The middle area of the lake is decidedly oligotrophic.

On the other hand, Melosira and Cyclotella predominated the lake waters adjacent to Wisconsin and Michigan harbors, and were sometimes numerous at shoreline stations between harbors. In addition, the total phytoplankton counts averaged about 1,500 per ml within the ten mile contour and less than 200 per ml at stations beyond the ten mile contour. In comparison, Lake Superior averages about 200 per ml at shoreline stations (3) and much less at the center of the lake. The relative high abundance of phytoplankton often predominated by Melosira and Cyclotella indicates that the shoreline waters of the southern basin of Lake Michigan are often highly productive biologically.

The changing character of the benthic fauna is reflected in increased populations of oligochaetes and decreased populations of amphipods in the past 30 years. This has been caused by the continuous sedimentation of organic matter that has gradually altered the habitat to one increasingly more favorable to oligochaetes. As the organic sedimentation continues the benthic fauna will change, and eventually become dominated by organisms typical of a eutrophic lake.

Lake Michigan has been receiving wastes at an ever-increasing rate since civilization first settled around its southern basin. From biological data it appears that wastes containing enormous quantities of nutrients do not disperse evenly throughout the lake, but tend to follow the shorelines, where they effect occasional high concentrations of phytoplankton of a kind uncommon in oligotrophic lakes. These periods of high biological productivity are symptoms of over-enrichment that precede eutrophy. This is substantiated by chemical analyses that revealed concentrations of phosphorus and nitrogen above the critical level, particularly in inshore areas of the southern basin. Further additions of nutrients to the system will certainly result in greater frequency of the periods of high biological productivity and will hasten the day when eutrophy will be manifested in a virtual population explosion of planktonic algae.

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TABLE 1 Phytoplankton Densities at the Surface-Lake Michigan
April-December 1962

Sampling Zone	No. of Stations	Frequency of Occurrence Organisms per milliliter at surface Ranges of Values			
		0-500	500-1000	1000-2500	2500-5000
Southeast Quadrant:					
1 mile offshore	34	17	11	4	2
4 miles offshore	22	19	1	1	1
7 miles offshore	14	12	2	0	0
10 miles offshore	11	11	0	0	0
Beyond 10 miles	13	10	3	0	0
Southwest Quadrant:					
1 mile offshore	40	24	9	7	0
4 miles offshore	54	43	6	4	1
7 miles offshore	22	21	1	0	0
10 miles offshore	25	23	1	1	0
Beyond 10 miles	24	23	1	0	0
Milwaukee Harbor and Vicinity:					
inside breakwater	32	0	1	7	24
outside breakwater	38	26	10	2	0
Chicago Harbor:	13	7	5	1	0
Northern Basin:					
1 mile offshore	14	7	5	1	1
4 miles offshore	11	6	3	1	1
7 miles offshore	0	-	-	-	-
10 miles offshore	0	-	-	-	-
Beyond 10 miles	19	17	2	0	0
Green Bay:	6	3	3	0	0

TABLE 2 Densities of the Predominant Genera of Phytoplankton at the Surface Lake Michigan, April-December, 1962

Sampling Zone		Organisms per Milliliter							
		Cyclo-Steph	Melosira	Synedra	Fragilaria	Tabellaria	Asterionella	Other	All Genera
Southeast Quadrant:									
1 mile offshore	min.	42	0	0	0	0	0	0	42
	max.	1876	280	1288	84	154	84	1512	4732
	ave.	409	27	101	14	28	15	201	795
4 miles offshore	min.	0	0	0	0	0	0	11	33
	max.	588	56	464	33	112	28	1820	3108
	ave.	107	6	38	13	17	20	178	379
7 miles offshore	min.	0	0	0	0	0	0	11	70
	max.	352	44	451	44	66	55	264	990
	ave.	73	6	57	8	10	4	73	231
10 miles offshore	min.	0	0	0	0	0	0	0	42
	max.	70	11	22	14	11	14	82	196
	ave.	42	2	3	1	1	4	44	97
beyond 10 miles	min.	0	0	0	0	0	0	0	66
	max.	242	50	350	33	75	100	220	638
	ave.	85	5	74	10	19	13	70	276
Southwest Quadrant:									
1 mile offshore	min.	0	0	0	0	0	0	0	33
	max.	308	1584	220	154	638	264	832	2112
	ave.	103	57	43	30	121	81	137	572

Table 2 (continued)
Densities of the Predominant Genera of Phytoplankton at the Surface
Lake Michigan, April-December, 1962

Sampling Zone		Organisms per Milliliter							
		Cyclo-Steph	Melosira	Synedra	Fragilaria	Tabellaria	Asterionella	Other	All Genera
4 miles offshore	min.	0	0	0	0	0	0	11	33
	max.	1100	242	224	154	462	374	330	2552
	ave.	134	15	28	26	58	43	93	397
7 miles offshore	min.	11	0	0	0	0	0	0	110
	max.	462	11	44	77	110	99	209	550
	ave.	100	2	13	21	30	35	51	252
10 miles offshore	min.	0	0	0	0	0	0	0	77
	max.	406	22	728	66	176	110	320	1298
	ave.	100	2	41	18	33	24	67	285
beyond 10 miles	min.	0	0	0	0	0	0	0	28
	max.	168	33	209	112	364	44	196	854
	ave.	51	3	60	11	29	12	61	227
Milwaukee Harbor:									
inside breakwater	min.	110	198	0	0	11	22	55	770
	max.	1298	2948	132	176	374	396	840	4778
	ave.	586	1900	43	42	105	197	265	3138
outside breakwater north of harbor entrance	min.	22	0	0	0	0	0	11	154
	max.	132	308	44	44	44	88	198	726
	ave.	49	47	15	16	25	52	52	256

Table 2 (continued)
Densities of the Predominant Genera of Phytoplankton at the Surface
Lake Michigan, April-December, 1962

Sampling Zone		Organisms per Milliliter							
		Cyclo-Steph	Melosira	Synedra	Fragilaria	Tabellaria	Asterionella	Other	All Genera
outside breakwater south of harbor entrance	min.	11	0	0	0	0	0	0	154
	max.	1188	3960	77	66	220	264	440	6182
	ave.	127	356	28	19	44	73	64	711
Chicago Harbor: Northern Basin:	min.	11	0	0	0	44	33	22	154
	max.	220	66	66	110	286	286	198	1078
	ave.	105	18	33	30	120	163	86	556
1 mile offshore	min.	0	0	22	0	0	0	44	132
	max.	1456	132	572	56	88	70	280	3052
	ave.	178	6	266	18	44	20	151	683
4 miles offshore	min.	0	0	11	0	0	0	56	154
	max.	308	84	682	44	56	33	2856	3668
	ave.	95	9	254	14	19	5	374	770
beyond 10 miles	min.	0	0	0	0	0	0	0	56
	max.	242	44	176	33	33	28	462	770
	ave.	55	10	96	7	8	4	100	280
Green Bay:	min.	11	0	0	11	0	22	11	209
	max.	99	22	638	55	33	286	242	968
	ave.	46	9	209	33	11	116	139	563

TABLE 3 Phytoplankton Densities at 50 Meters or Deeper
Lake Michigan, April-December 1962

Sampling Zone	No. of Stations	Frequency of Occurrence Organisms per Milliliter — Ranges of Values 0 - 500	500 - 1000	1000 - 2500	2500 - 5000
Southeast Quadrant:					
1 mile offshore	1	1	0	0	0
4 miles offshore	0	-	-	-	-
7 miles offshore	7	6	1	0	0
10 miles offshore	5	5	0	0	0
Beyond 10 miles	10	10	0	0	0
Southwest Quadrant:					
1 mile offshore	0	-	-	-	-
4 miles offshore	0	-	-	-	-
7 miles offshore	2	2	0	0	0
10 miles offshore	5	5	0	0	0
Beyond 10 miles	19	19	0	0	0
Northern Basin:					
1 mile offshore	1	1	0	0	0
4 miles offshore	4	2	2	0	0
7 miles offshore	0	-	-	-	-
10 miles offshore	1	1	0	0	0
Beyond 10 miles	17	17	0	0	0

Table 4 Densities of the Predominant Genera of Phytoplankton
Lake Michigan, April-December, 1962

Sampling Zone	No. of Stations		Organisms per Milliliter at 50 Meters or Deeper							
			Cyclo.-Steph.	Melosira	Synedra	Fragilaria	Tabellaria	Asterionella	Other	All Genera
Southeast Quadrant:										
1 mile offshore	1	Min.	11	0	88	33	0	11	11	154
		Max.	11	0	88	33	0	11	11	154
		Ave.	11	0	88	33	0	11	11	154
7 miles offshore	7	Min.	0	0	0	0	0	0	0	55
		Max.	132	66	110	88	88	44	110	528
		Ave.	64	17	41	25	33	19	25	224
10 miles offshore	5	Min.	33	0	11	0	0	0	0	66
		Max.	66	11	33	11	44	11	44	154
		Ave.	51	2	24	2	18	2	9	108
Beyond 10 miles	10	Min.	0	0	0	0	0	0	0	55
		Max.	132	198	33	66	44	0	110	440
		Ave.	42	50	10	17	10	0	33	162
Southwest Quadrant:										
7 miles offshore	2	Min.	33	0	0	11	55	0	0	110
		Max.	33	0	0	55	110	22	77	275
		Ave.	33	0	0	33	83	11	39	199
10 miles offshore	5	Min.	11	0	0	0	0	0	0	44
		Max.	44	11	22	22	44	22	88	198
		Ave.	22	2	11	11	22	9	33	110

Table 4 (Continued) Densities of the Predominant Genera of Phytoplankton

Lake Michigan, April-December, 1962

Sampling Zone	No. of Stations		Organisms per Milliliter at 50 Meters or Deeper							
			Cyclo.-Steph.	Melosira	Synedra	Fragilaria	Tabellaria	Asterionella	Other	All Genera
Beyond 10 miles	19	Min.	0	0	0	0	0	0	0	33
		Max.	110	44	132	33	44	33	88	286
		Ave.	39	6	30	9	10	5	25	125
Northern Basin:										
1 mile offshore	1	Min.	66	0	88	0	44	0	110	308
		Max.	66	0	88	0	44	0	110	308
		Ave.	66	0	88	0	44	0	110	308
4 Miles offshore	4	Min.	22	0	44	0	0	0	22	308
		Max.	176	44	506	44	154	66	110	880
		Ave.	83	22	259	11	72	33	66	534
10 miles offshore	1	Min.	99	22	77	0	33	0	33	264
		Max.	99	22	77	0	33	0	33	264
		Ave.	99	22	77	0	33	0	33	264
Beyond 10 miles	17	Min	0	0	0	0	0	0	0	11
		Max.	66	55	132	44	66	22	66	352
		Ave.	19	15	30	6	16	4	16	106

Table 6 Amphipod (Scuds) Populations, Lake Michigan
April-December 1962

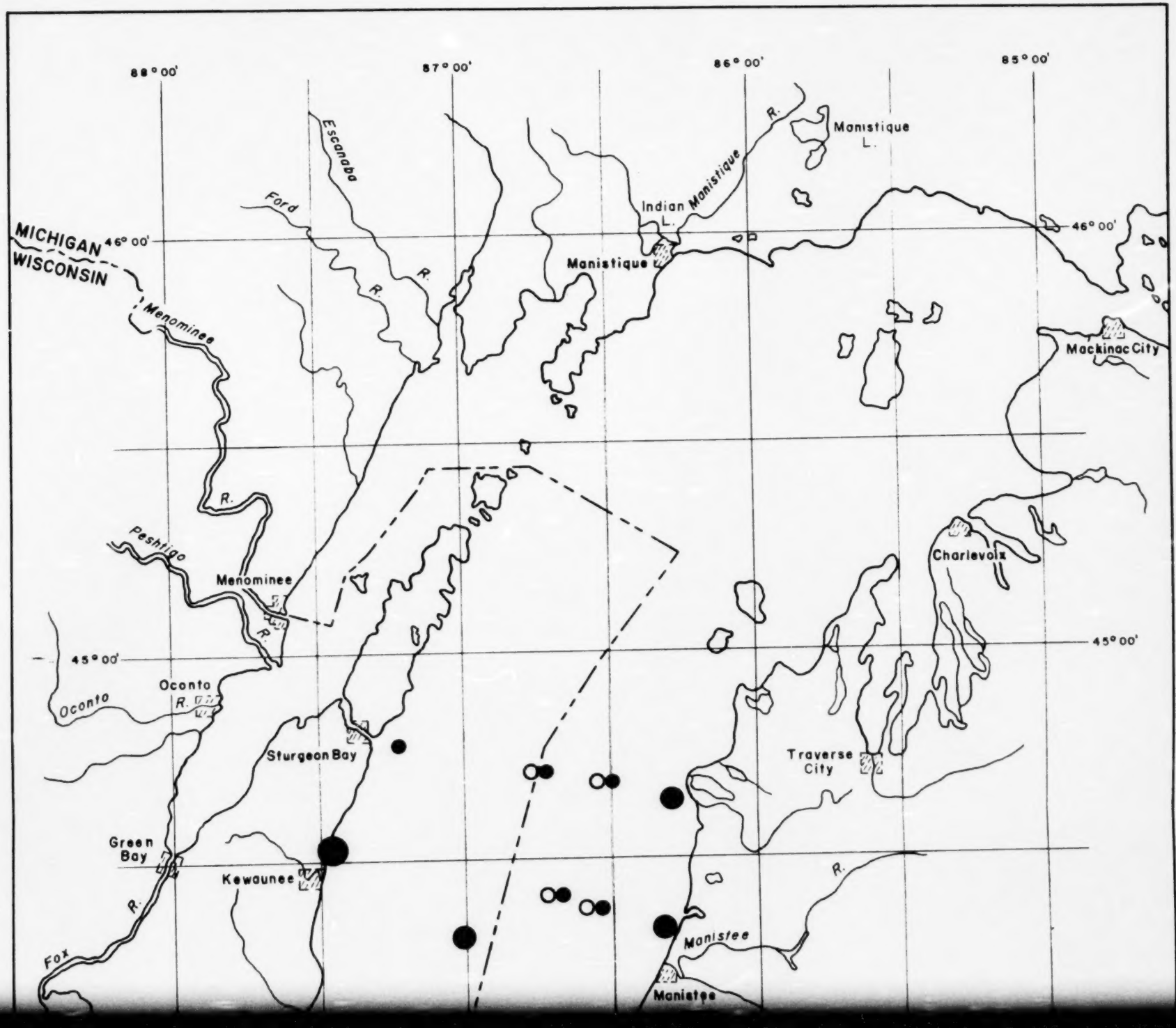
Sampling Zone	No. of Stations	Frequency of Occurrence Percent of Amphipods to Total Number Ranges of Values 0-25	26-50	51-75	76-100	Remarks
Southeast Quadrant:						
1 mile offshore	32	12	2	9	9	9 of the 0-25% stations
4 miles offshore	20	3	5	8	4	were subject to wave action.
7 miles offshore	14	1	5	7	1	
10 miles offshore	10	2	4	4	0	
Beyond 10 miles	10	1	4	5	0	
Southwest Quadrant:						
1 mile offshore	4	1	0	2	1	midge larve also abundant
4 miles offshore	7	2	2	3	0	at 7 and 10 mile stations
7 miles offshore	8	3	1	3	1	
10 miles offshore	6	2	1	2	1	
Beyond 10 miles	16	0	9	5	2	
Milwaukee Harbor and Vicinity:	7	7	0	0	0	No Amphipods in Milwaukee Harbor
Northern Basin:						
1 mile offshore	13	5	3	2	3	
4 miles offshore	10	4	2	2	2	
7 miles offshore	0	-	-	-	-	
10 miles offshore	0	-	-	-	-	
Beyond 10 miles	22	4	7	9	2	
Green Bay:	6	2	4	0	0	

TABLE 7 Oligochaeta (Sludgeworms) Populations, Lake Michigan
April-December, 1962

Sampling Zone	No. of Stations	Frequency of Occurrence Percent of Oligochaeta to Total Number Ranges of Values 0 - 25	26 - 50	51 - 75	76 - 100	Remarks
Southeast Quadrant:						
1 mile offshore	32	18	7	4	3	9 of the 0 - 25 stations
4 miles offshore	20	8	5	6	1	were subject to wave action
7 miles offshore	14	1	9	4	0	
10 miles offshore	10	0	5	3	2	
Beyond 10 miles	10	1	6	3	0	
Southwest Quadrant:						
1 mile offshore	4	2	1	1	0	
4 miles offshore	7	1	3	2	1	
7 miles offshore	8	1	5	0	2	
10 miles offshore	6	2	2	1	1	
Beyond 10 miles	16	4	7	5	0	
Milwaukee Harbor and Vicinity	7	1	1	0	5	Oligochaetes dominant
Northern Basin:						
1 mile offshore	13	8	3	2	0	
4 miles offshore	10	4	2	3	1	
7 miles offshore						
10 miles offshore						
Beyond 10 miles	22	5	11	3	3	
Green Bay:	6	3	1	0	2	

TABLE 8 Light Penetration (Secchi Disc), Lake Michigan
April-December, 1962

Sampling Zone	No. of Stations	Frequency of Occurrence Transparency in Meters Ranges of Values			
		0 - 2	2.1 - 6	6.1 - 12	12.1 - 20
Southeast Quadrant:					
1 mile offshore	38	1	34	3	0
4 miles offshore	19	1	15	3	0
7 miles offshore	15	1	8	7	0
10 miles offshore	11	0	3	8	0
Beyond 10 miles	10	0	5	5	0
Southwest Quadrant:					
1 mile offshore	57	19	38	0	0
4 miles offshore	52	2	47	3	0
7 miles offshore	23	0	16	7	0
10 miles offshore	27	0	22	5	0
Beyond 10 miles	32	0	8	21	3
Milwaukee Harbor and Vicinity:					
inside breakwater	33	33	0	0	0
outside breakwater	44	16	28	0	0
Chicago Harbor:	17	10	7	0	0
Northern Basin:					
1 mile offshore	10	1	9	0	0
4 miles offshore	10	0	5	4	1
Beyond 10 miles	16	0	2	12	2
Green Bay:	6	0	6	0	0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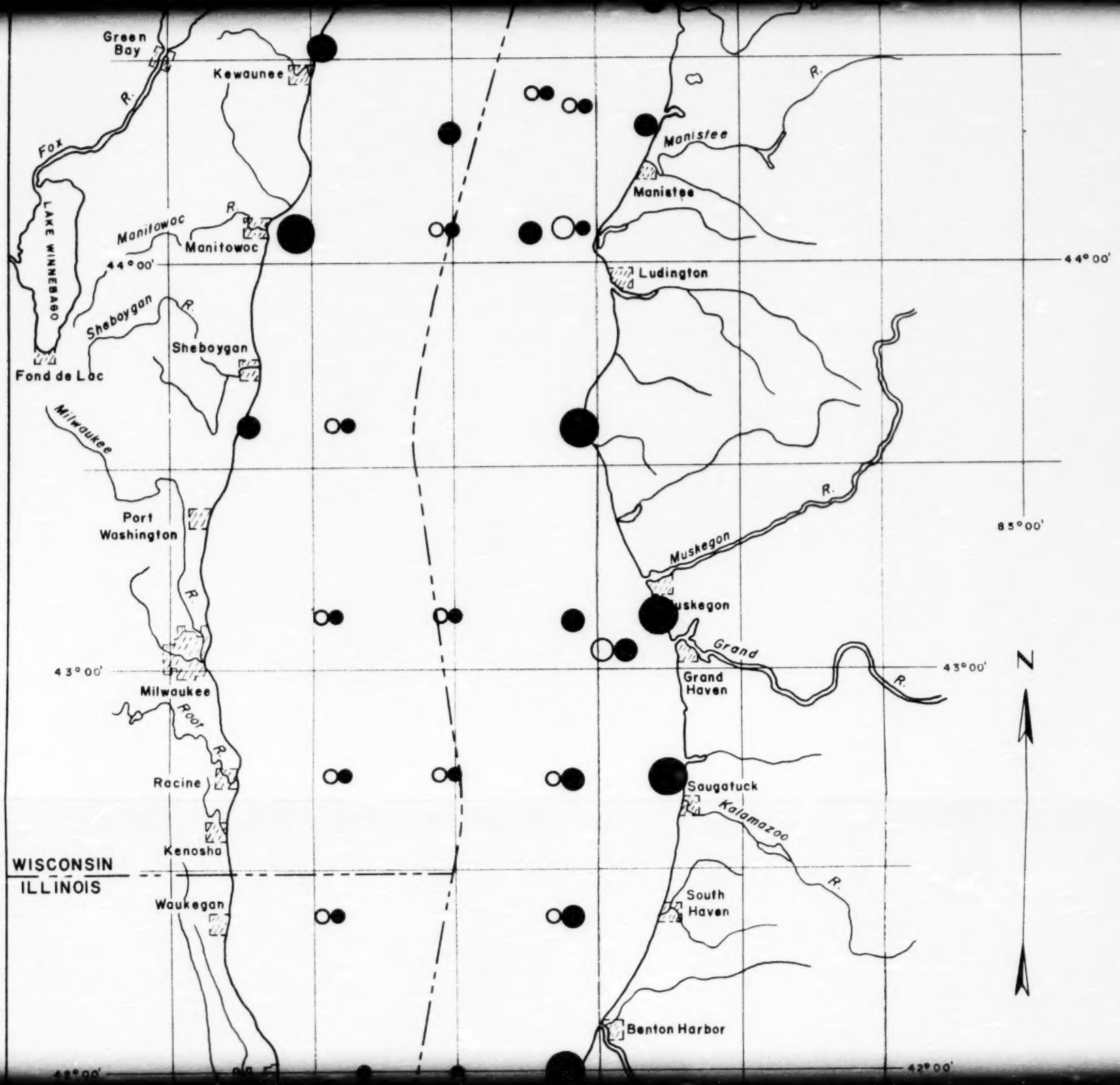
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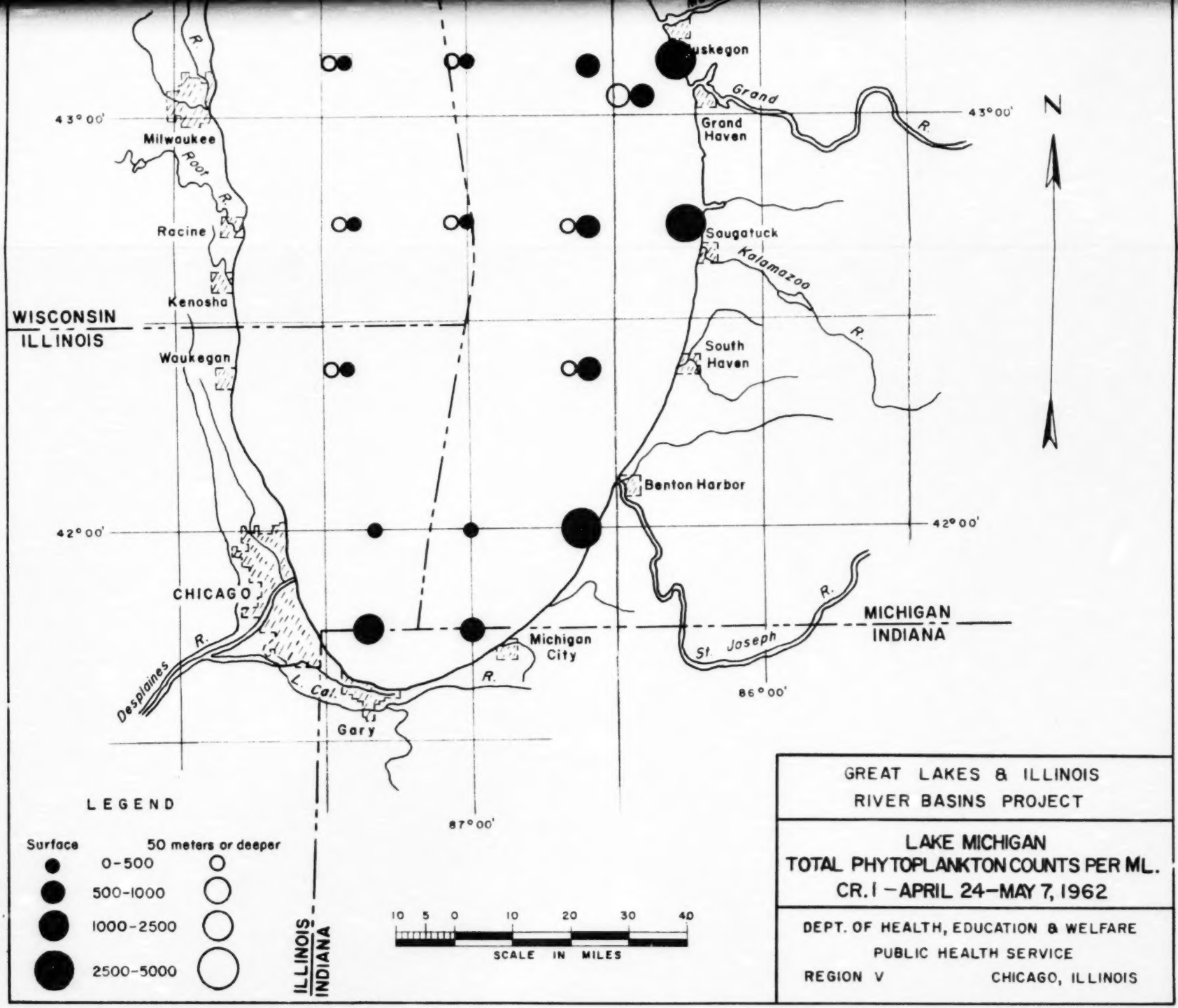
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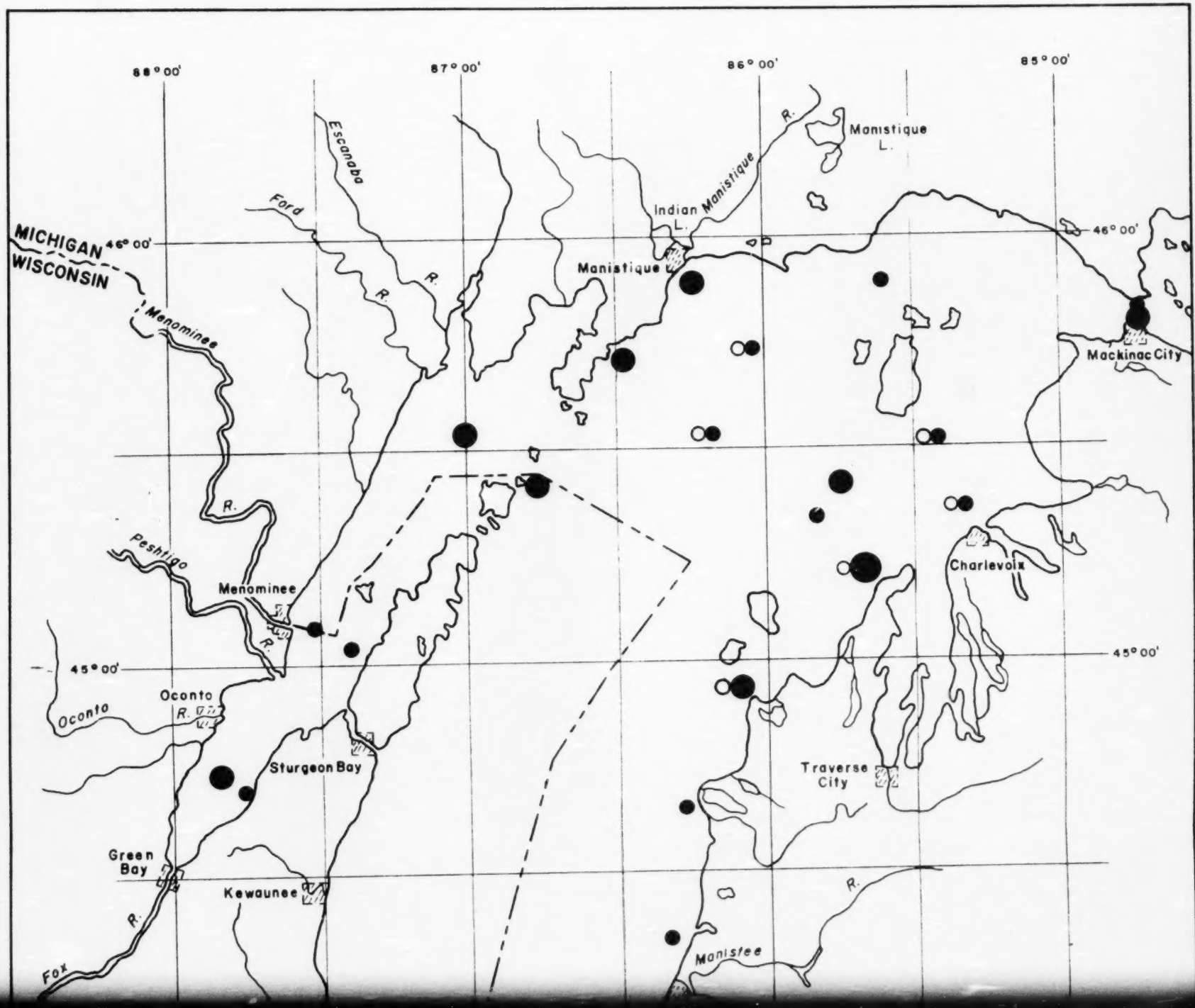
SCALE IN MILES
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
LAKE MICHIGAN
TOTAL PHYTOPLANKTON COUNTS PER ML.
CR. I – APRIL 24–MAY 7, 1962
DEPT. OF HEALTH, EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS

FIGURE I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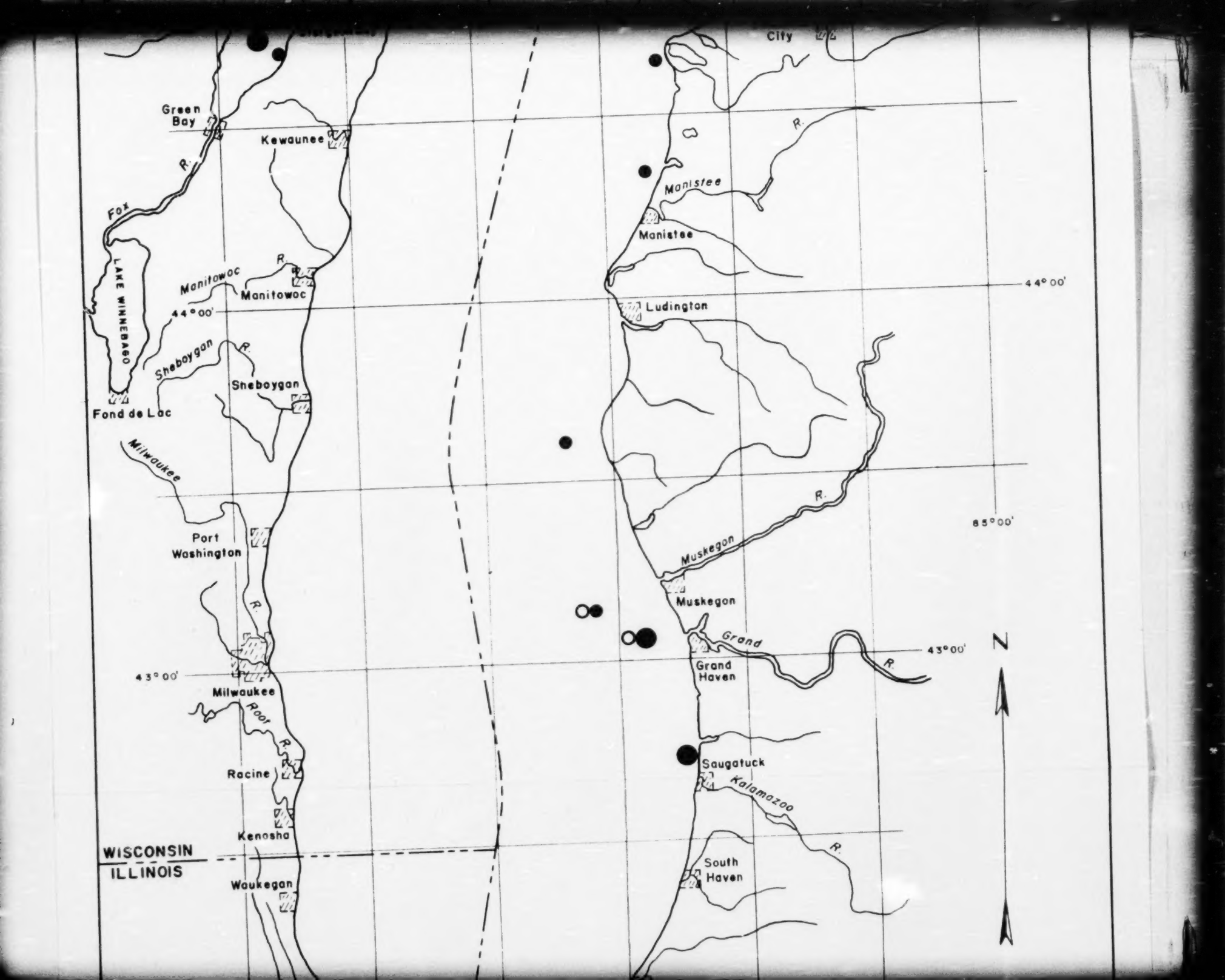
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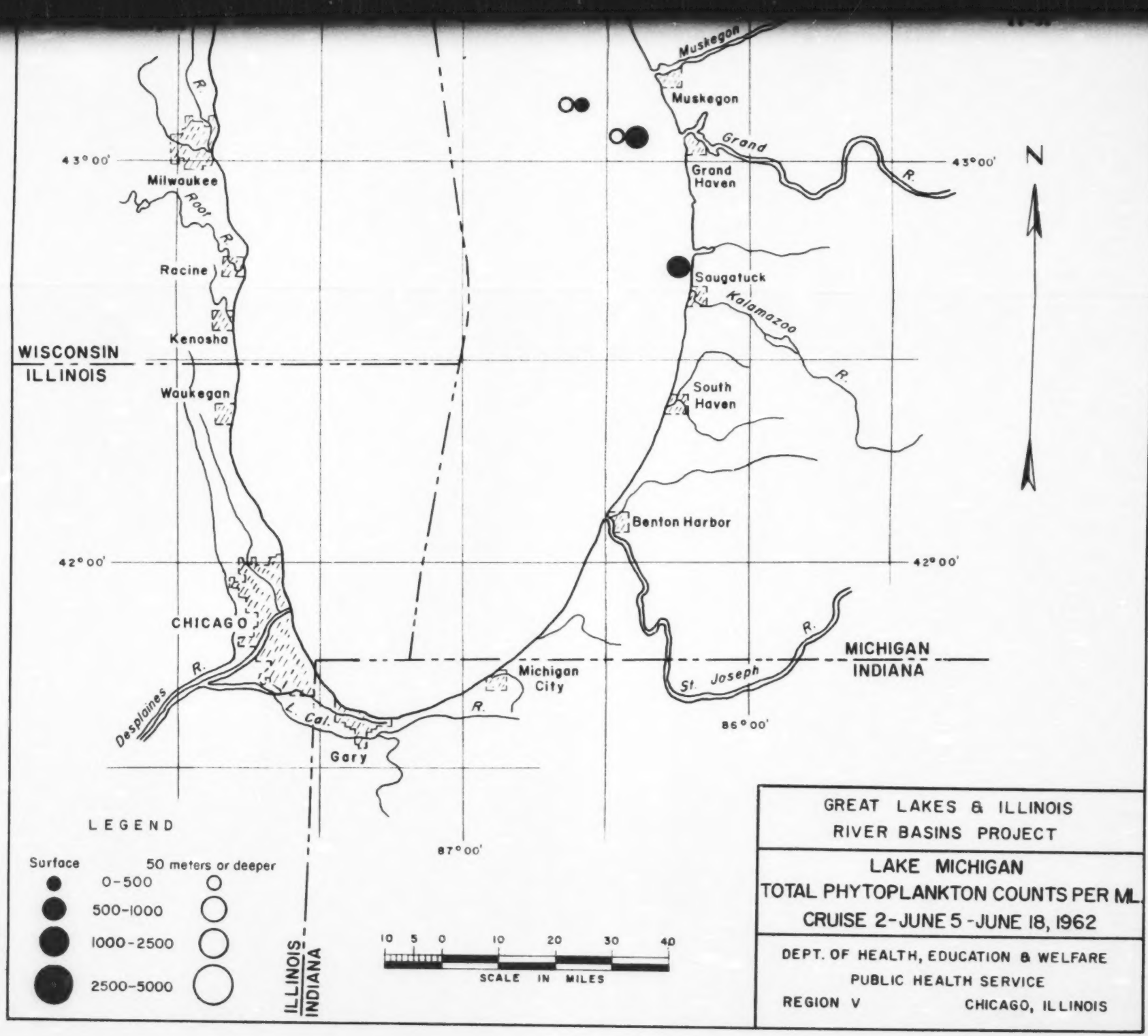
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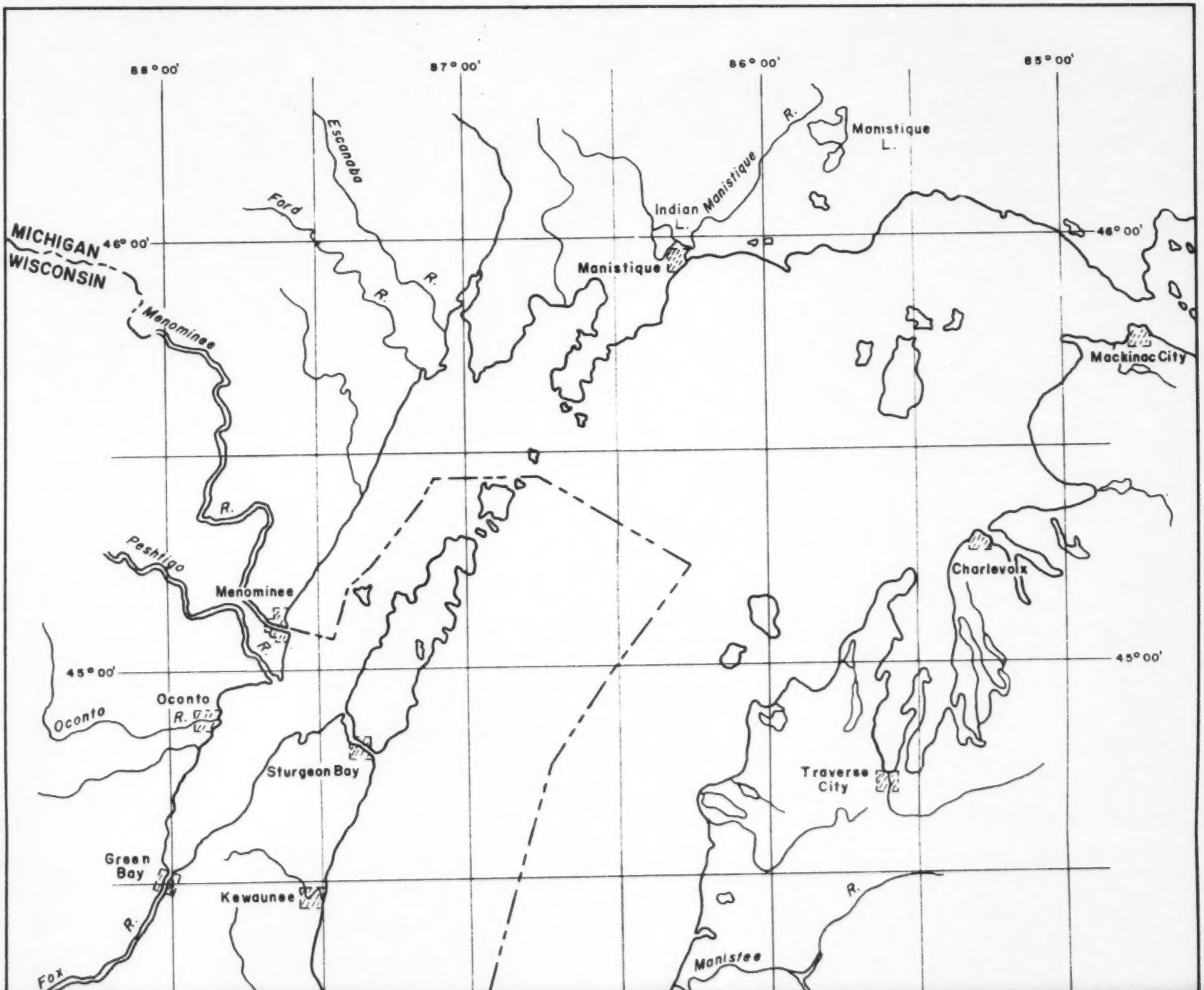
SCALE IN MILES
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
LAKE MICHIGAN
TOTAL PHYTOPLANKTON COUNTS PER ML.
CRUISE 2-JUNE 5 -JUNE 18, 1962
DEPT. OF HEALTH, EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS

FIGURE 2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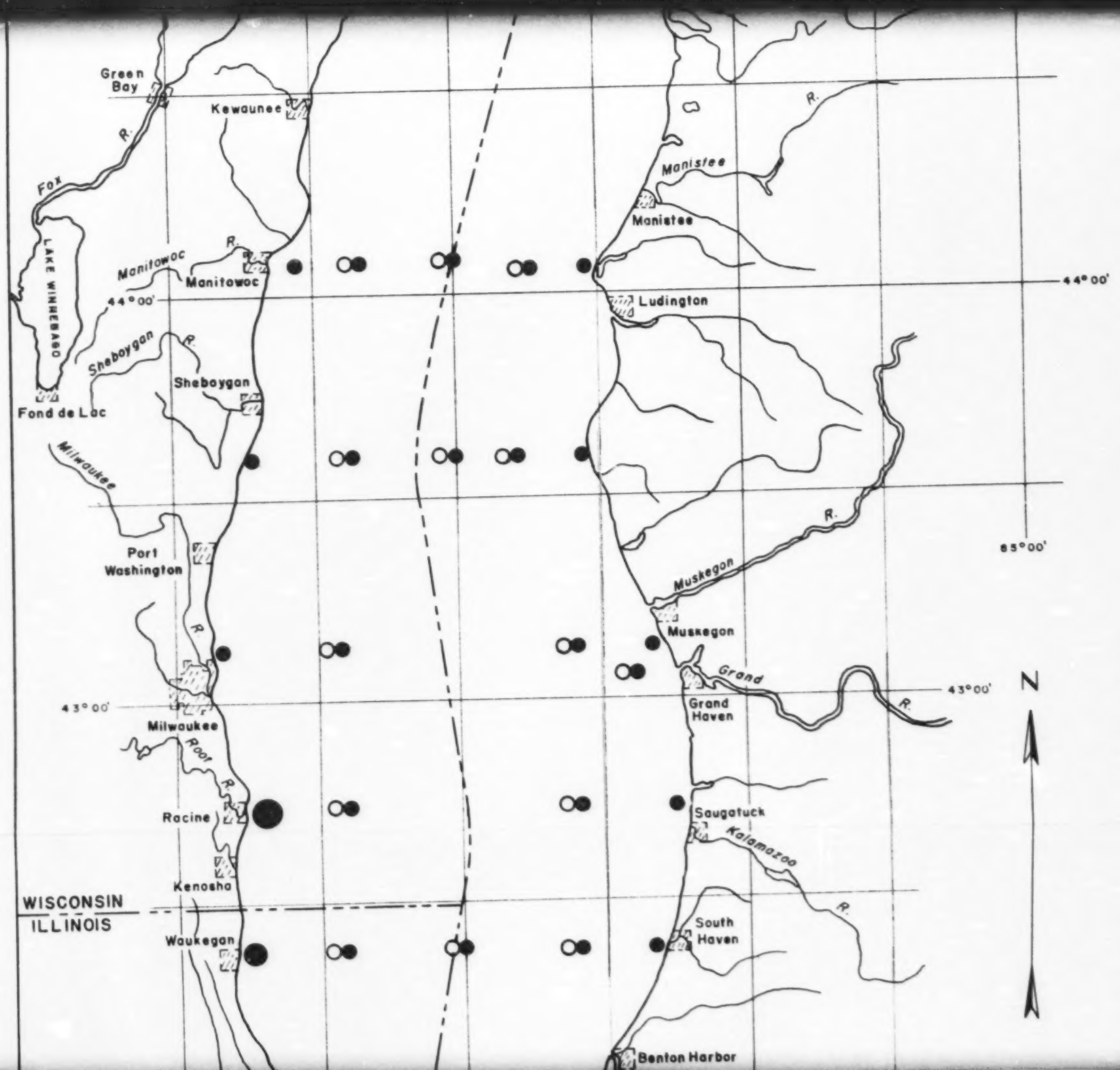
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South Haven
Benton Harbor

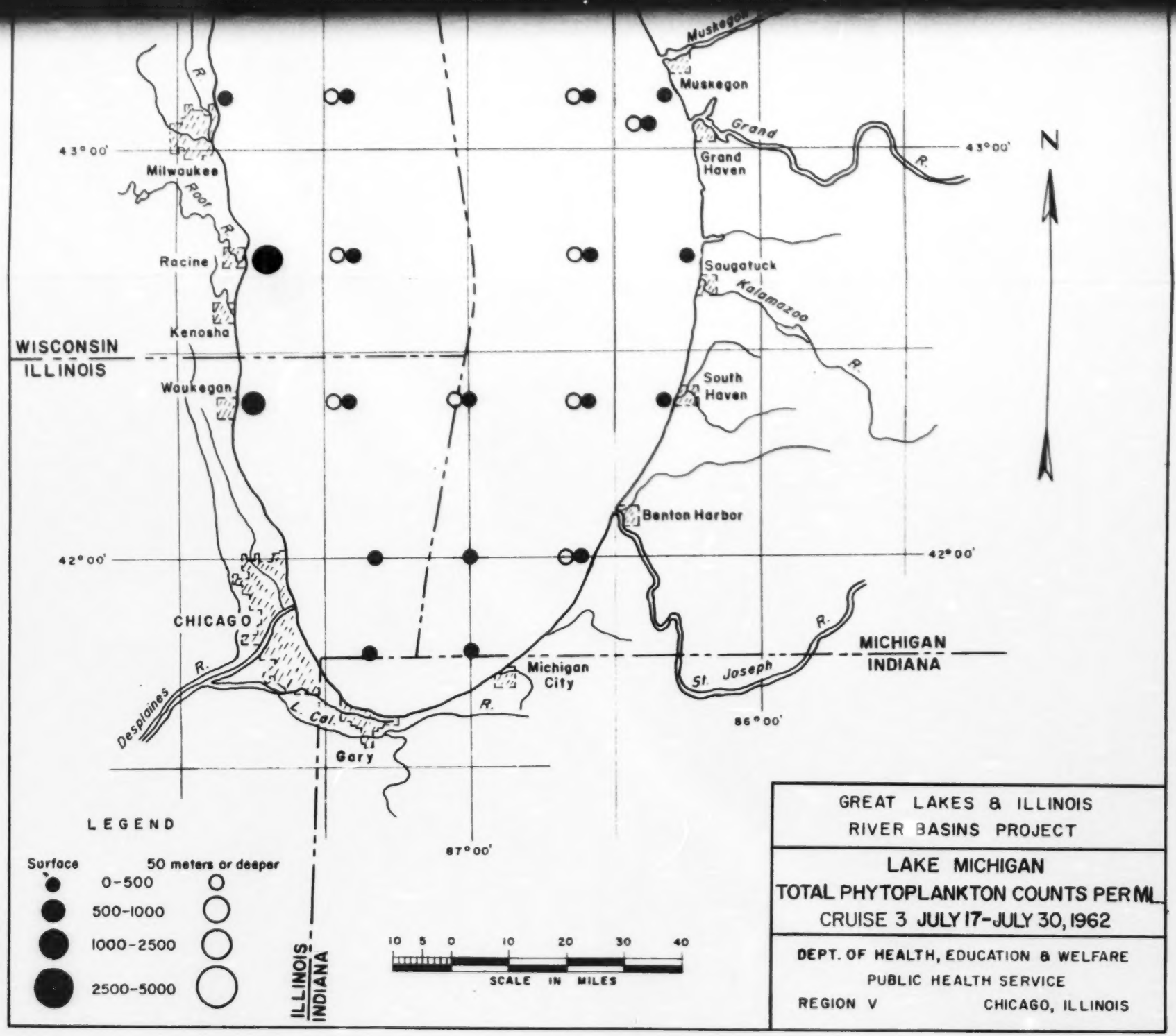
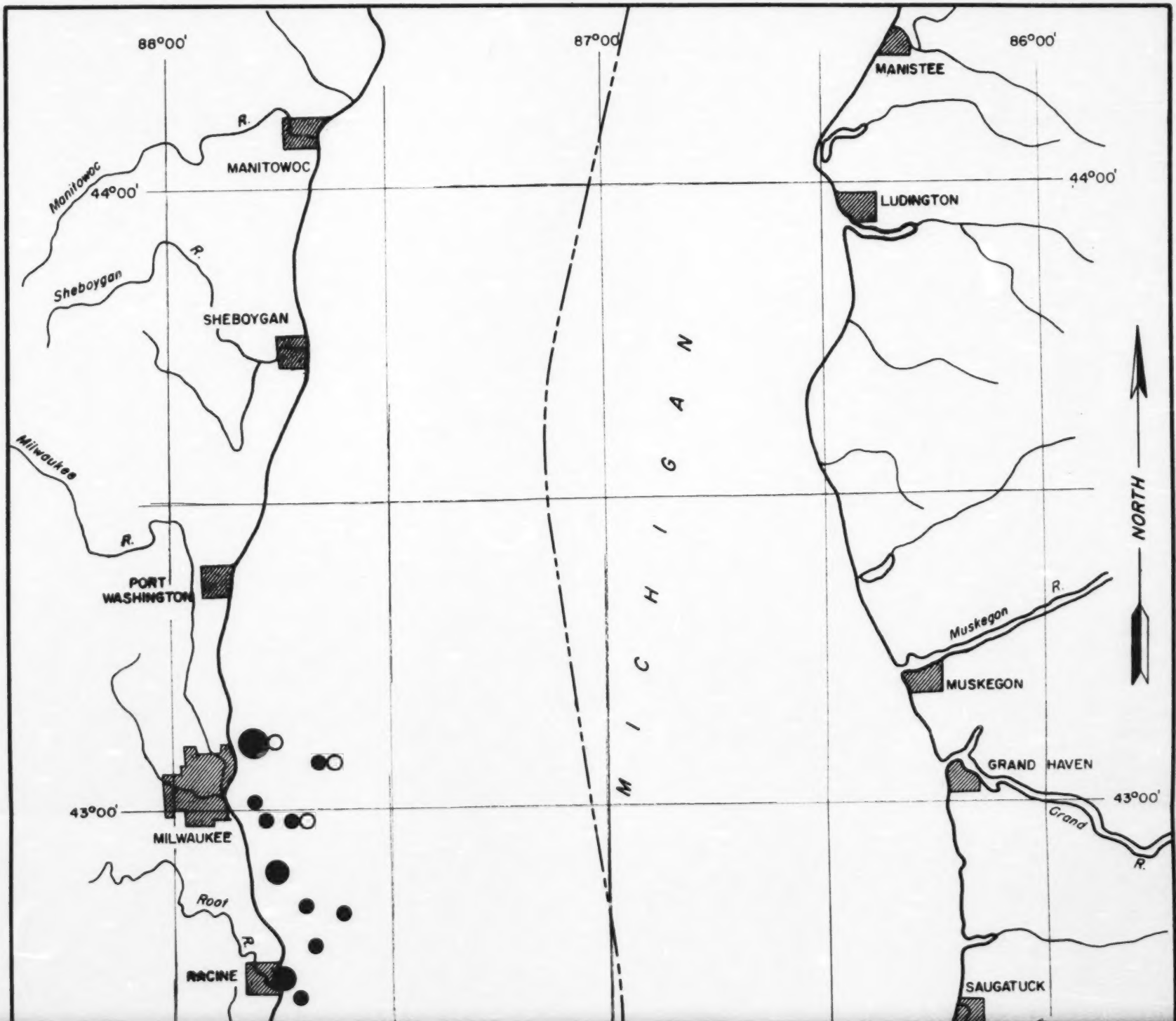
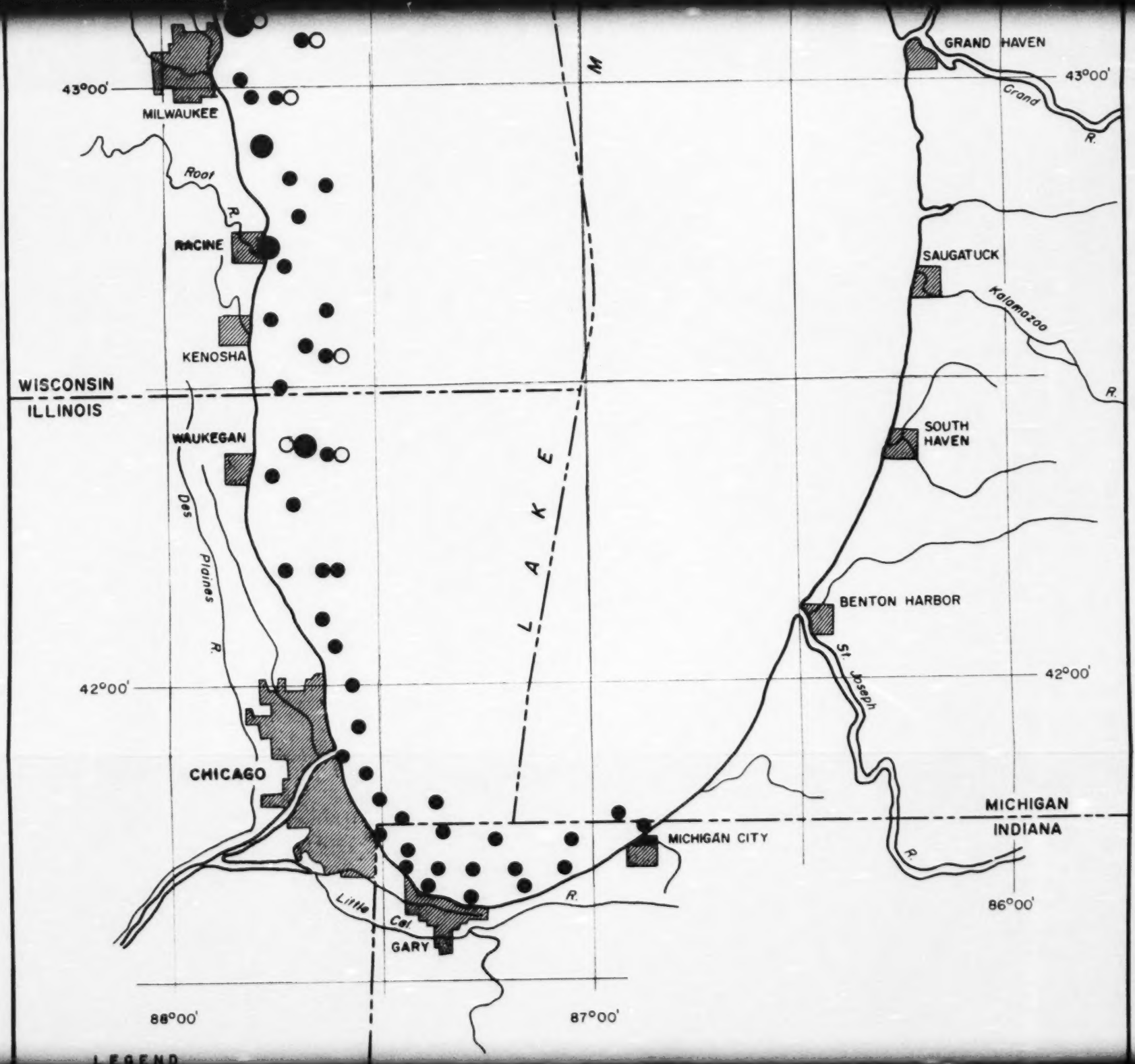

Muskegon
Muskegon
Grand
Grand Haven
R.
43° 00'
43° 00'
N
Milwaukee
Root
R.
Racine
Saugatuck
Kalamazoo
R.
Kenosha
WISCONSIN
ILLINOIS
Waukegan
South Haven
Benton Harbor
42° 00'
42° 00'
CHICAGO
R.
MICHIGAN
INDIANA
Michigan City
St. Joseph
R.
Des plaines
R.
L. Cal.
R.
86° 00'
Gary
87° 00'
LEGEND
Surface
50 meters or deeper
0-500
500-1000
1000-2500
2500-5000
ILLINOIS
INDIANA
10 5 0 10 20 30 40
SCALE IN MILES
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
LAKE MICHIGAN
TOTAL PHYTOPLANKTON COUNTS PER ML
CRUISE 3 JULY 17-JULY 30, 1962
DEPT. OF HEALTH, EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS

FIGURE 3


88°00'
87°00'
86°00'
MANISTEE
MANITOWOC R.
MANITOWOC
44°00'
LUDINGTON
SHEBOYGAN R.
SHEBOYGAN
MILWAUKEE R.
PORT WASHINGTON
MICHIGAN
NORTH
MUSKEGON R.
MUSKEGON
GRAND HAVEN
43°00'
GRAND R.
MILWAUKEE
ROOT R.
RACINE
SAUGATUCK


43°00'
MILWAUKEE
Root
R.
RACINE
KENOSHA
WISCONSIN
ILLINOIS
WAUKEGAN
Des
Plaines
R.
42°00'
CHICAGO
L A K E
M
GRAND HAVEN
43°00'
Grand
R.
SAUGATUCK
Kalamazoo
R.
SOUTH
HAVEN
BENTON HARBOR
St. Joseph
42°00'
MICHIGAN
INDIANA
MICHIGAN CITY
R.
86°00'
Little
Cal.
GARY
R.
88°00'
87°00'

LEGEND

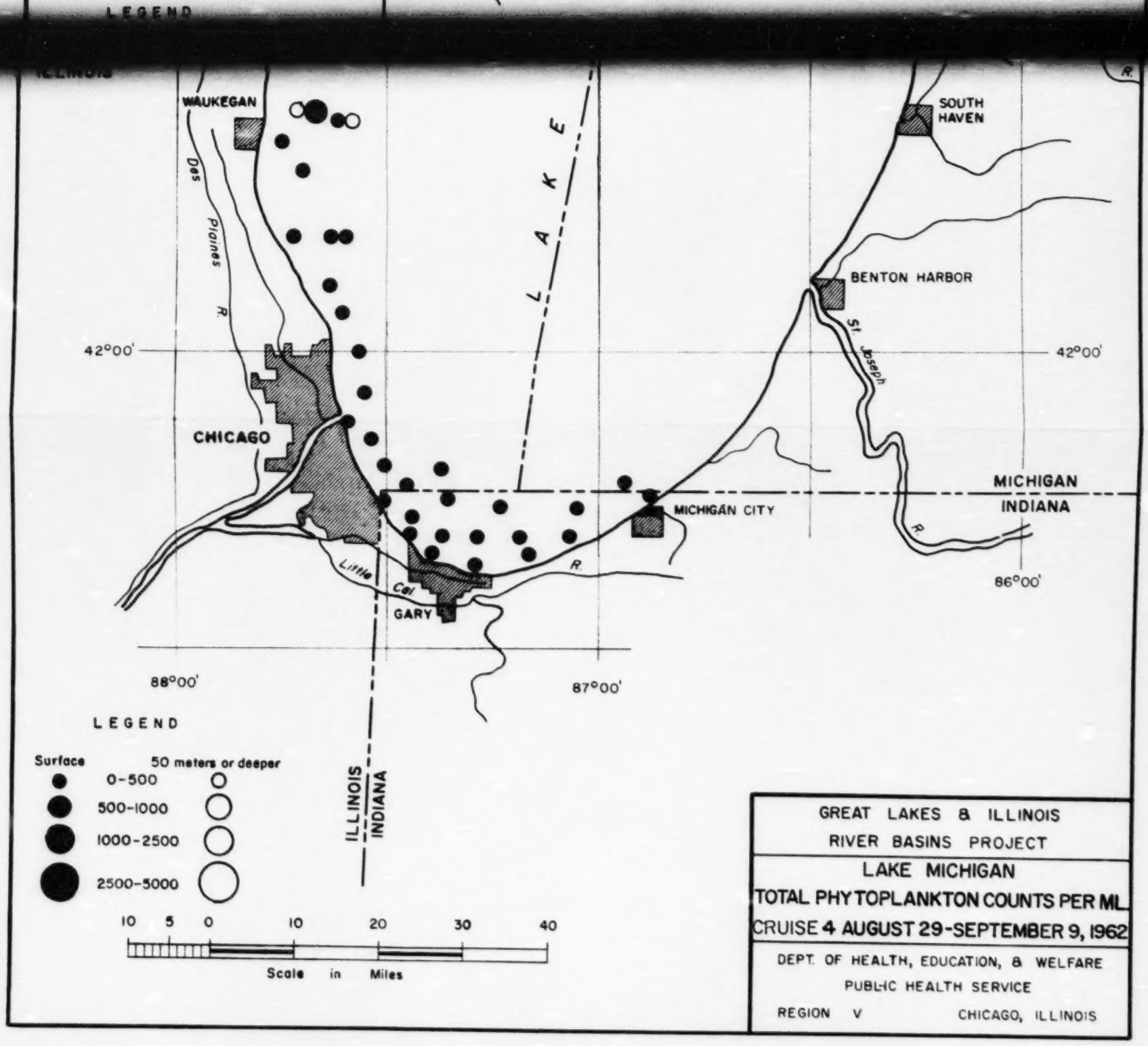
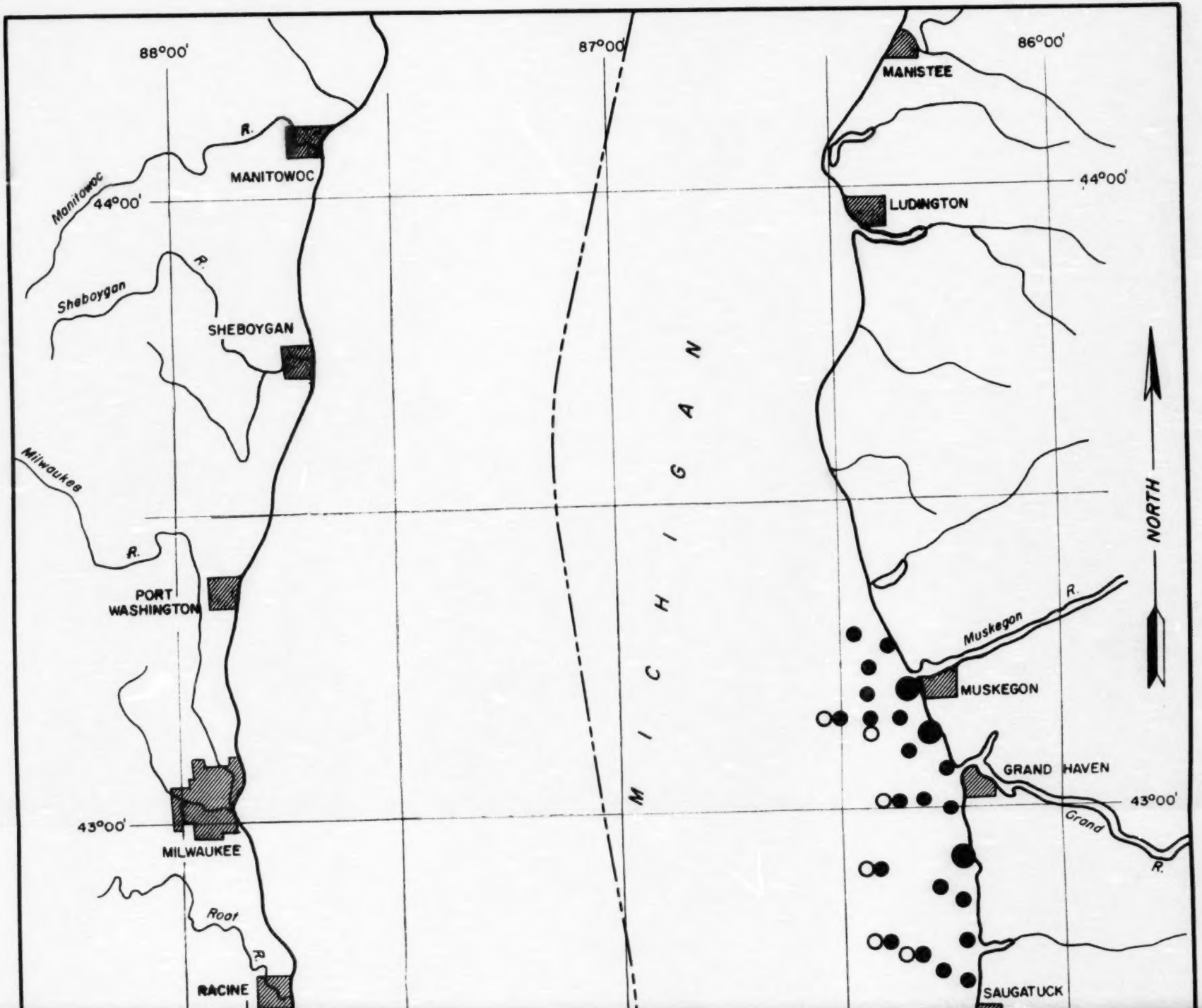
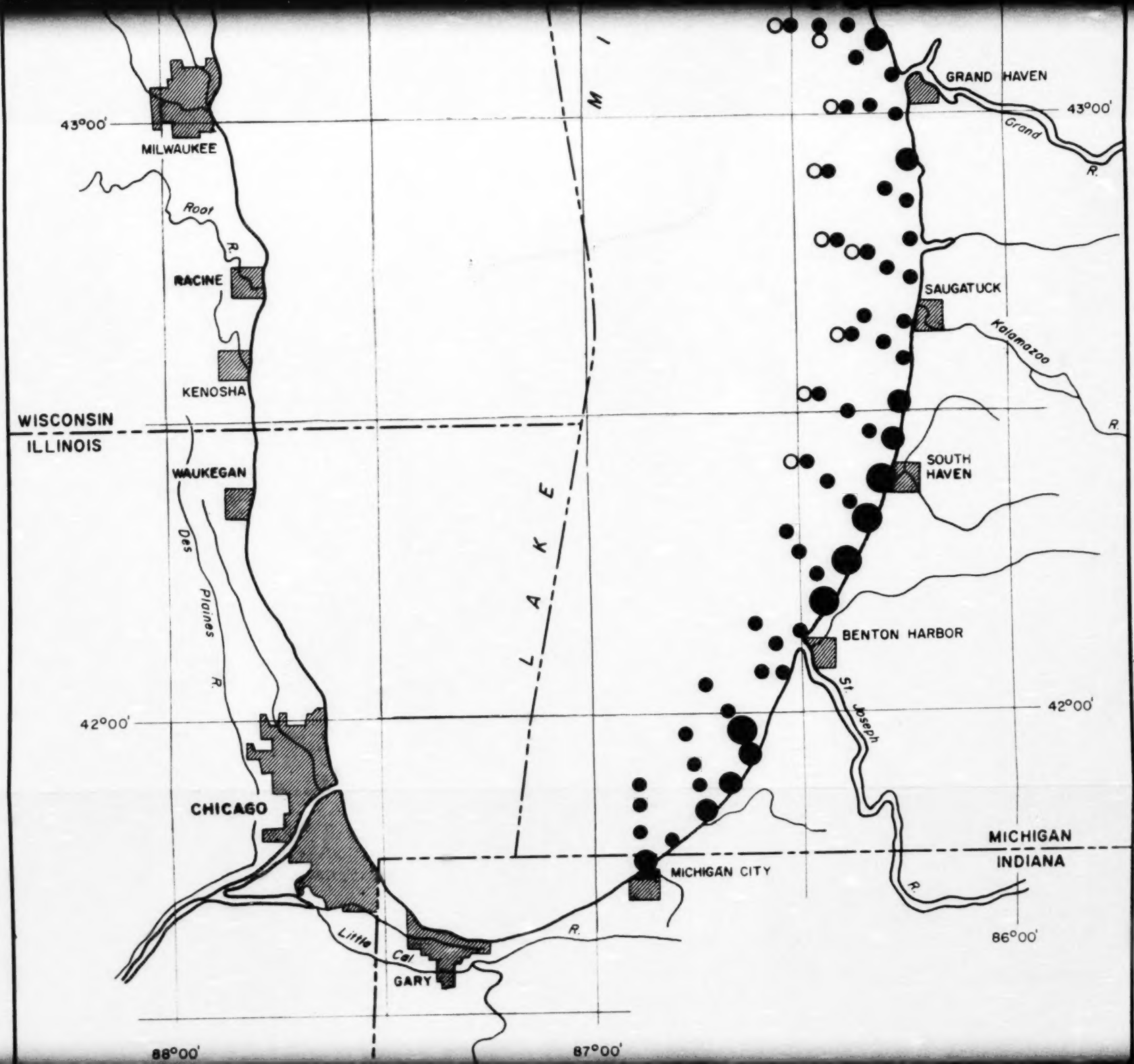

LEGEND
WAUKEGAN
Des Plaines R.
LAKE
SOUTH HAVEN
BENTON HARBOR
St. Joseph R.
42°00'
CHICAGO
MICHIGAN CITY
MICHIGAN
INDIANA
Little Cal R.
GARY
86°00'
88°00'
87°00'
LEGEND
Surface
50 meters or deeper
0-500
500-1000
1000-2500
2500-5000
ILLINOIS
INDIANA
10 5 0 10 20 30 40
Scale in Miles
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
LAKE MICHIGAN
TOTAL PHYTOPLANKTON COUNTS PER ML.
CRUISE 4 AUGUST 29-SEPTEMBER 9, 1962
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 4


88°00'
87°00'
86°00'
MANISTEE
R.
Manitowoc
MANITOWOC
44°00'
LUDINGTON
Sheboygan
R.
SHEBOYGAN
MICHIGAN
Milwaukee
R.
PORT
WASHINGTON
NORTH
Muskegon
R.
MUSKEGON
GRAND HAVEN
43°00'
Grand
R.
MILWAUKEE
Root
R.
RACINE
SAUGATUCK


MILWAUKEE
Root R.
RACINE
KENOSHA
WISCONSIN
ILLINOIS
WAUKEGAN
Des Plaines R.
CHICAGO
Little Cal R.
GARY
MICHIGAN CITY
MICHIGAN
INDIANA
BENTON HARBOR
St. Joseph R.
SOUTH HAVEN
SAUGATUCK
Kalamazoo R.
GRAND HAVEN
Grand R.
LAKE MICHIGAN
43°00'
42°00'
88°00'
87°00'
86°00'

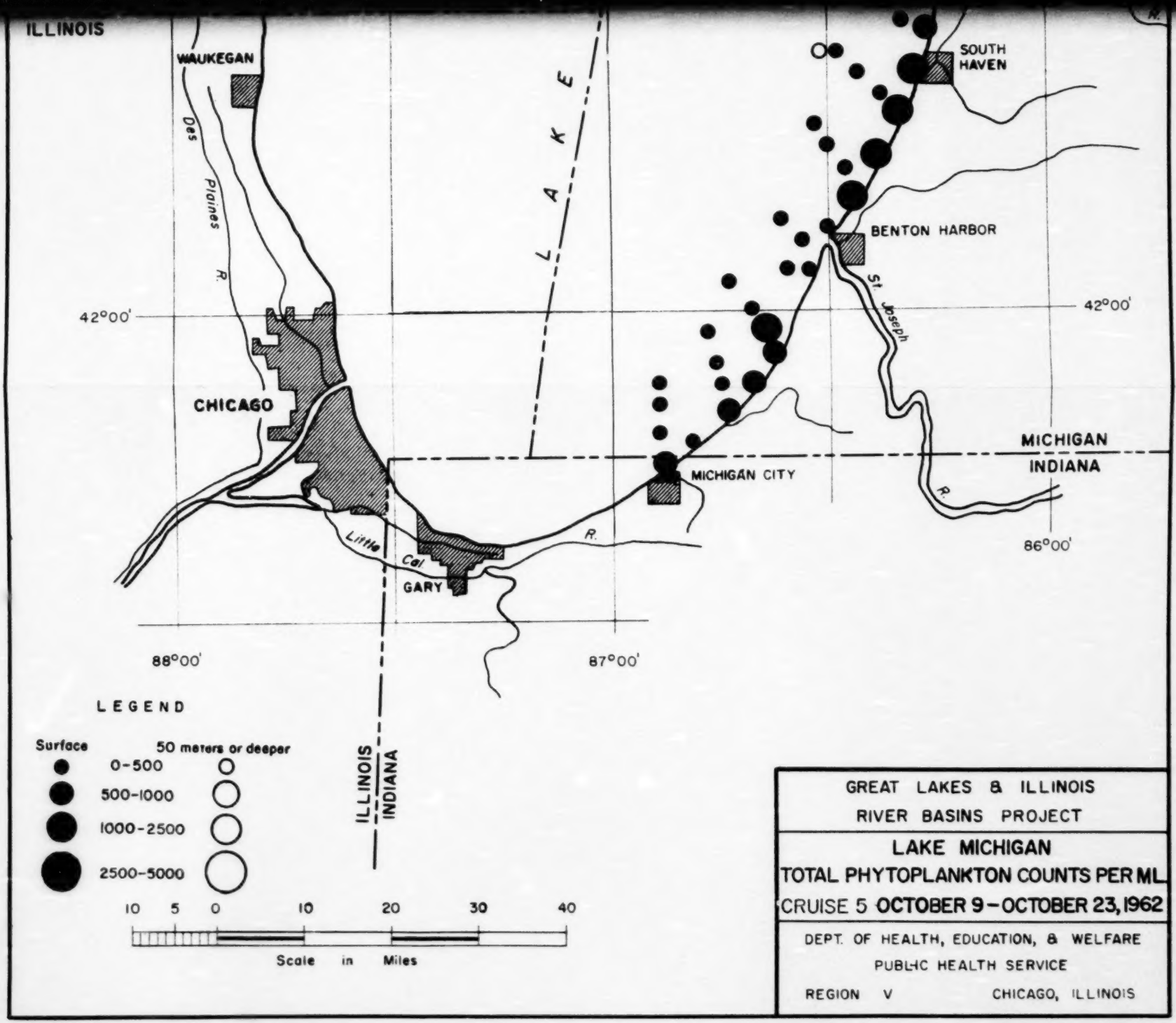
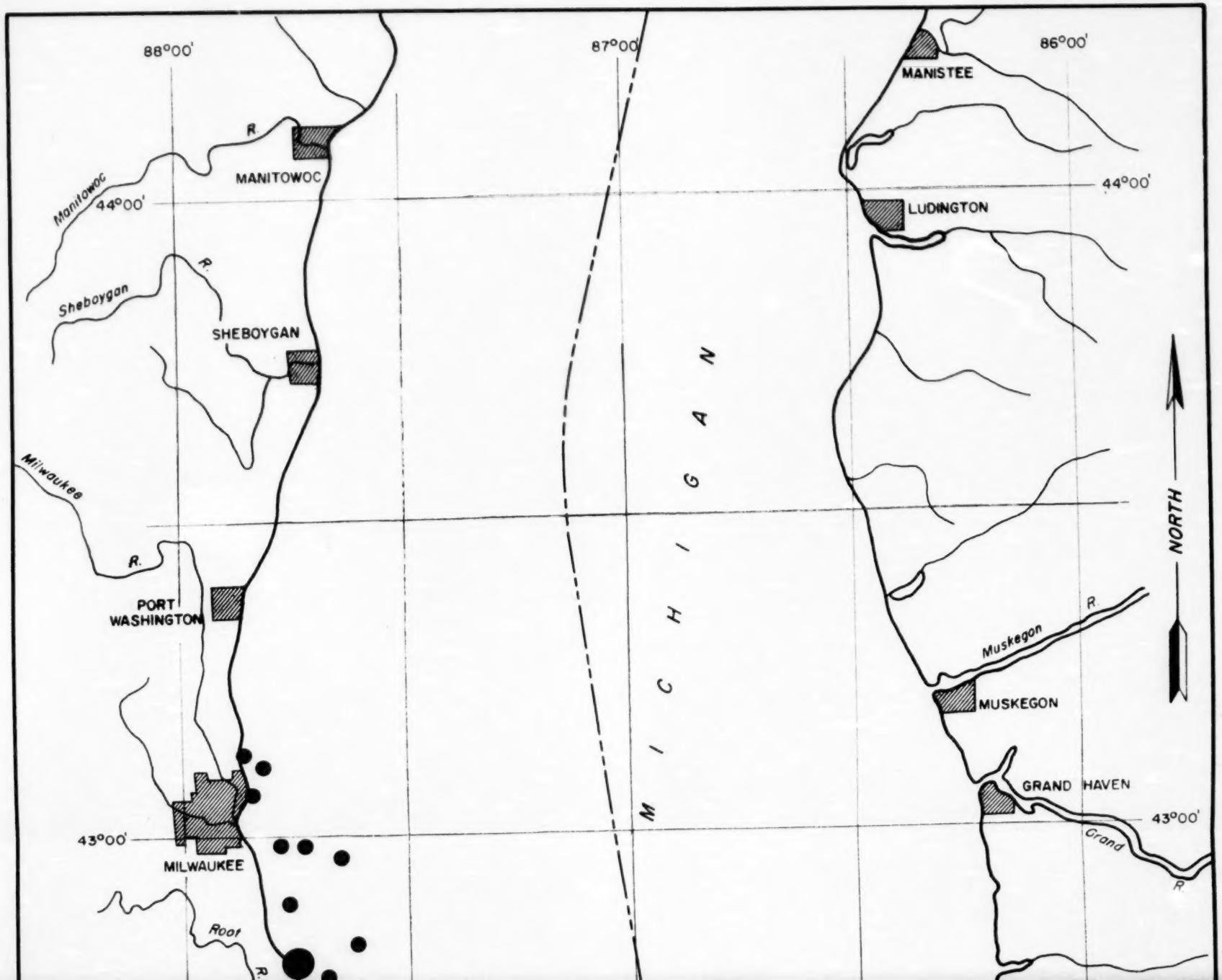
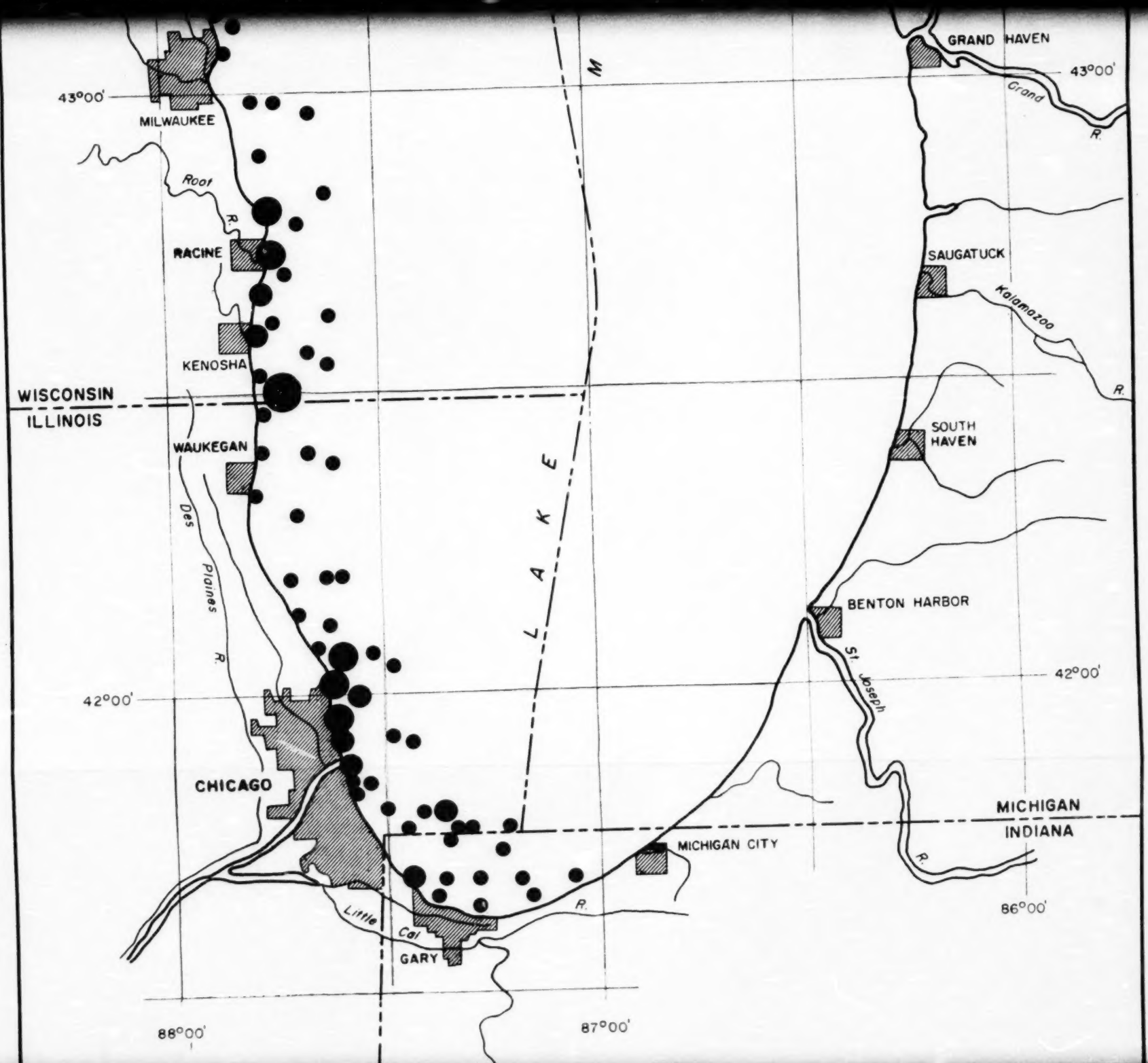
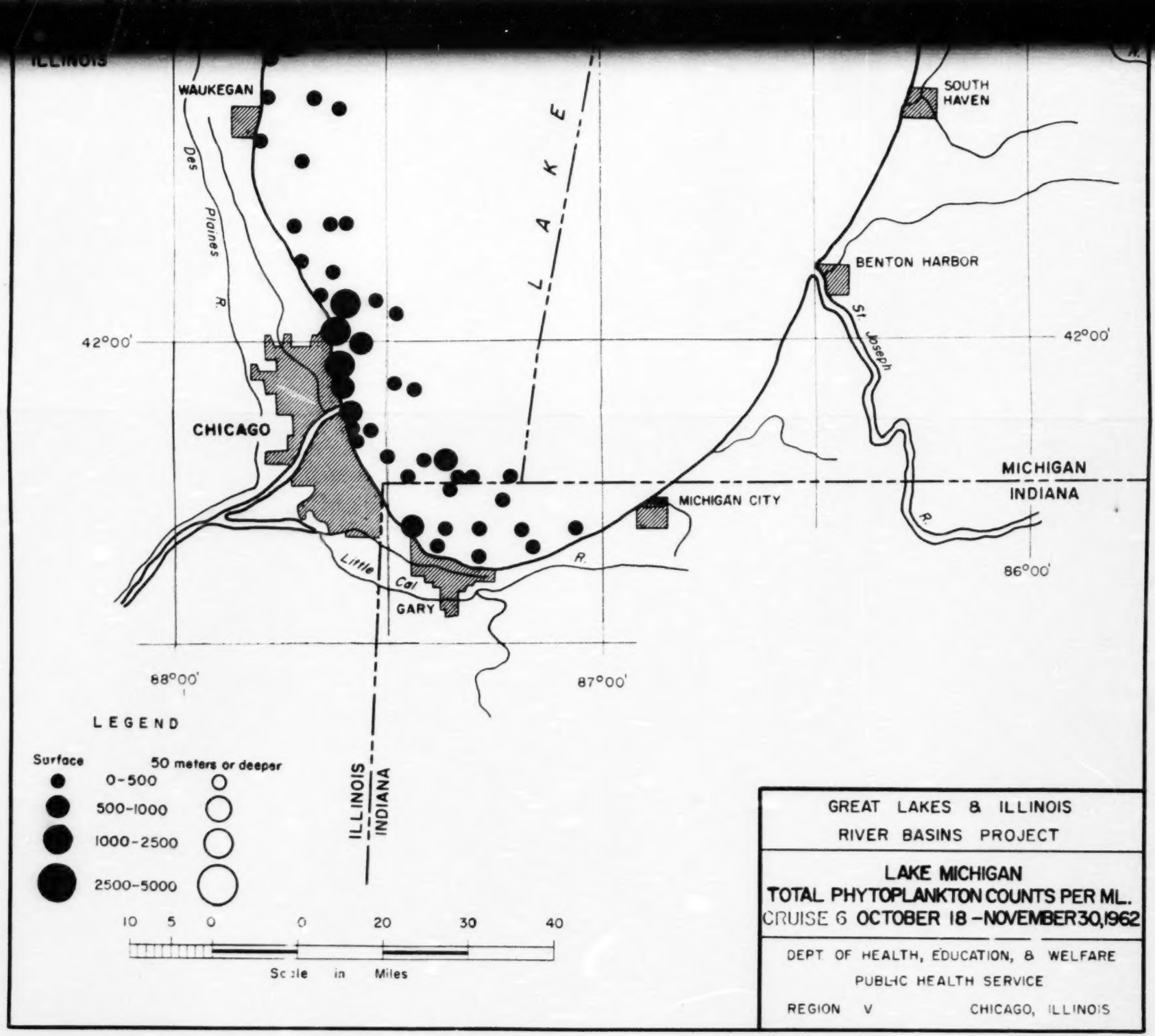

ILLINOIS
WAUKEGAN
Des Plaines R.
LAKE
SOUTH HAVEN
BENTON HARBOR
St. Joseph R.
42°00'
CHICAGO
MICHIGAN
INDIANA
MICHIGAN CITY
Little Cal R.
GARY
86°00'
88°00'
87°00'
ILLINOIS
INDIANA
LEGEND
Surface
50 meters or deeper
0-500
500-1000
1000-2500
2500-5000
10 5 0 10 20 30 40
Scale in Miles
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
LAKE MICHIGAN
TOTAL PHYTOPLANKTON COUNTS PER ML.
CRUISE 5 OCTOBER 9 – OCTOBER 23, 1962
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 5


88°00'
87°00'
86°00'
MANISTEE
MANITOWOC
R.
Manitowoc
44°00'
LUDINGTON
Sheboygan
R.
SHEBOYGAN
MICHIGAN
NORTH
Milwaukee
R.
PORT
WASHINGTON
Muskegon
R
MUSKEGON
GRAND HAVEN
43°00'
MILWAUKEE
Grand
R.
Root
R.


GRAND HAVEN
43°00'
Grand
R.
MILWAUKEE
Root
R.
RACINE
SAUGATUCK
Kalamazoo
R.
KENOSHA
WISCONSIN
ILLINOIS
SOUTH
HAVEN
WAUKEGAN
Des
Plaines
R.
LAKE
MICHIGAN
BENTON HARBOR
St. Joseph
42°00'
CHICAGO
MICHIGAN
INDIANA
MICHIGAN CITY
R.
86°00'
Little
Cal
R.
GARY
88°00'
87°00'

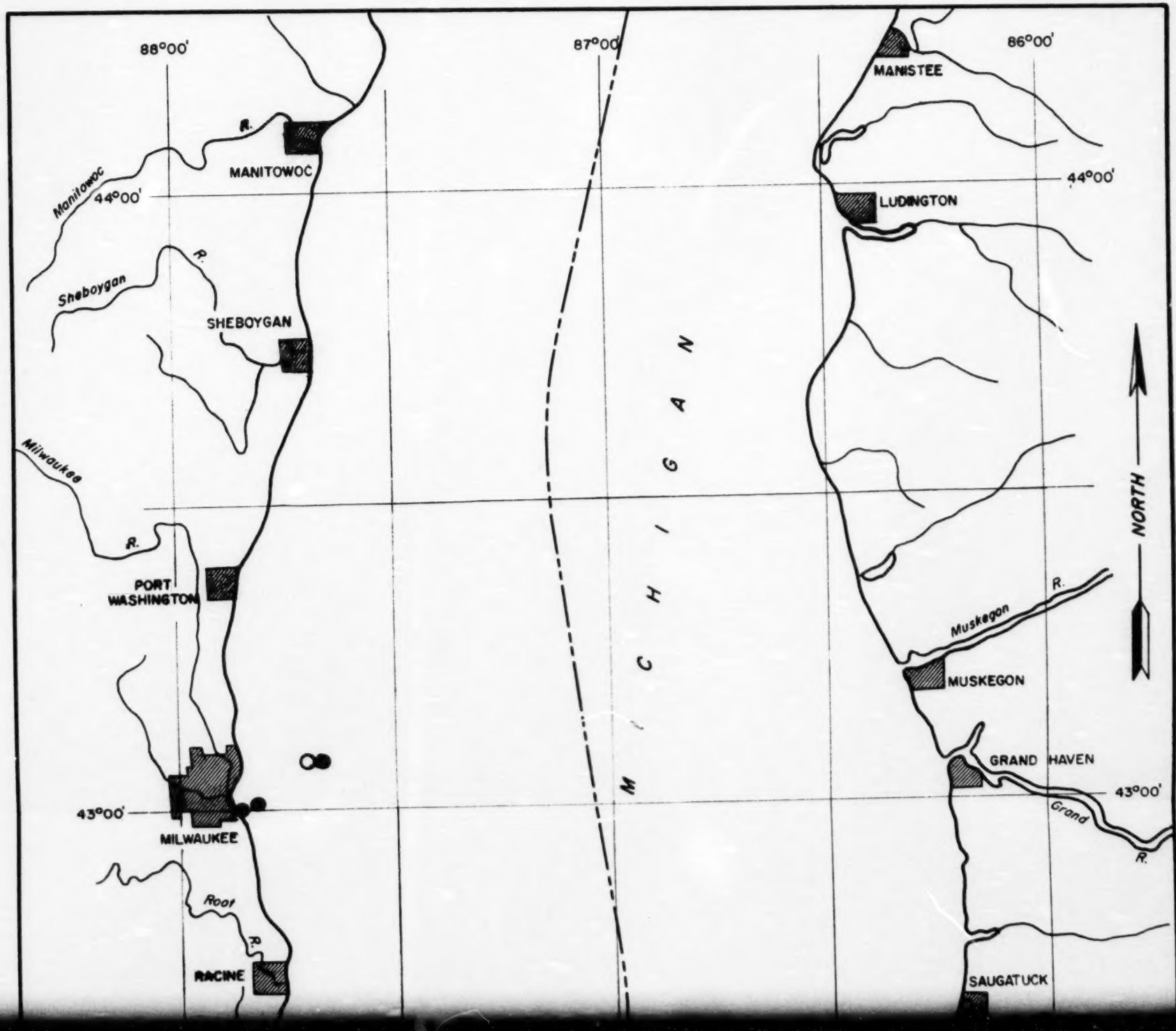


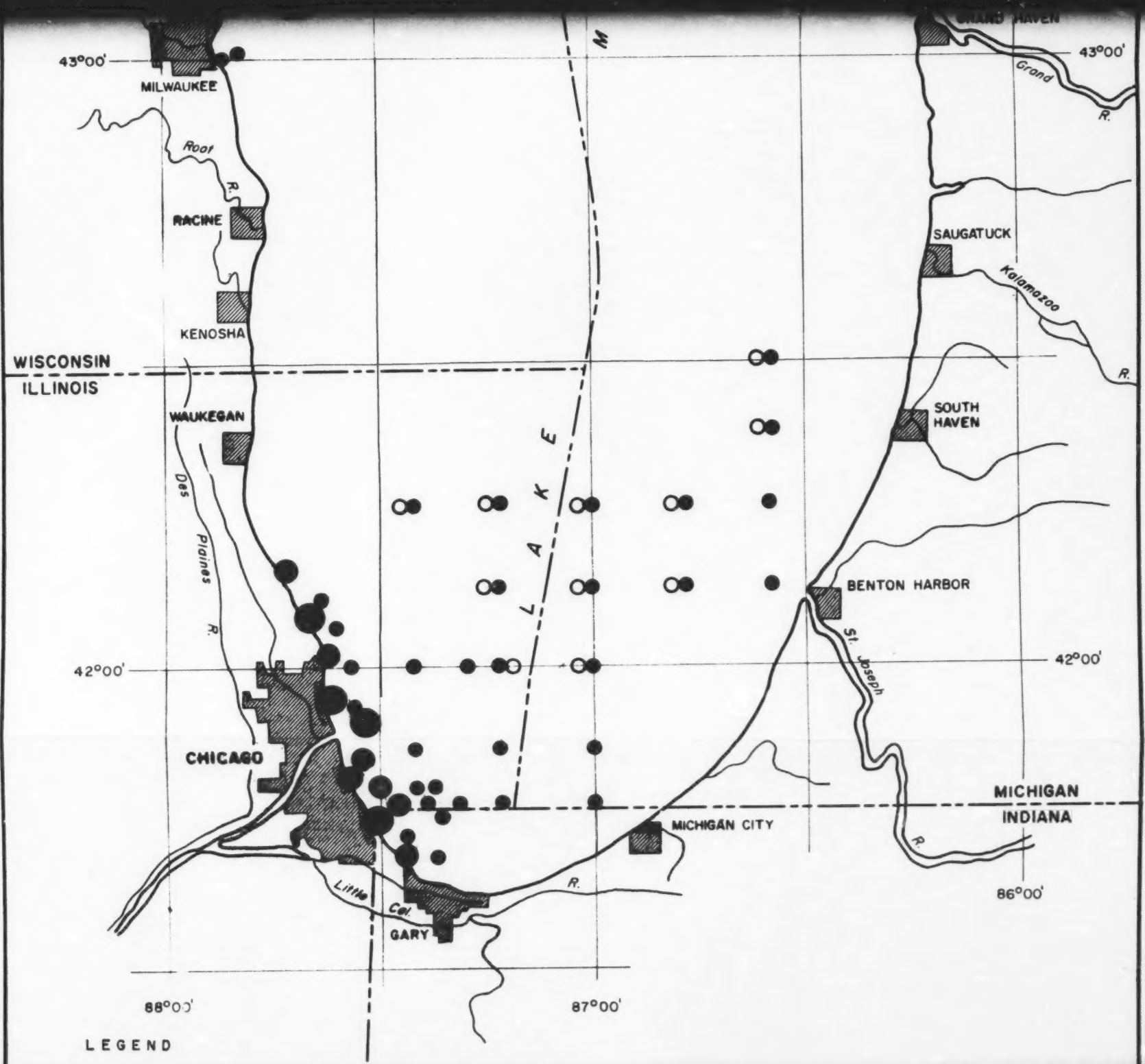
GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

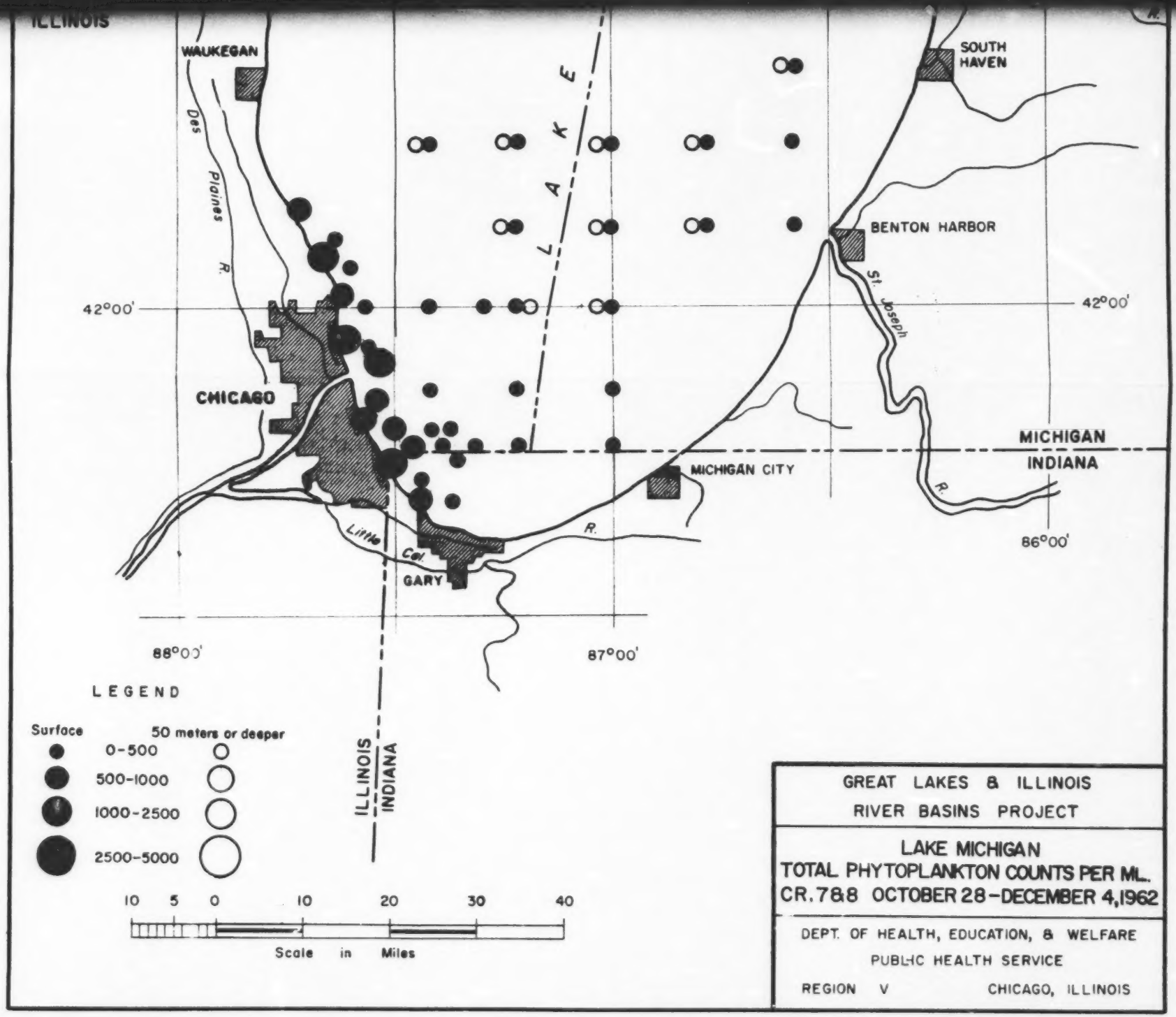
LAKE MICHIGAN
TOTAL PHYTOPLANKTON COUNTS PER ML.
CRUISE 6 **OCTOBER 18 – NOVEMBER 30, 1962**

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 6


88°00'
87°00'
86°00'
MANISTEE
R.
MANITOWOC
Manitowoc
44°00'
LUDINGTON
Sheboygan
R.
SHEBOYGAN
MICHIGAN
Milwaukee
R.
PORT
WASHINGTON
NORTH
Muskegon
R.
MUSKEGON
GRAND HAVEN
43°00'
Grand
R.
MILWAUKEE
Root
R.
RACINE
SAUGATUCK


43°00'
MILWAUKEE
Root
R.
RACINE
KENOSHA
WISCONSIN
ILLINOIS
WAUKEGAN
Des
Plaines
R.
42°00'
CHICAGO
L A K E
M
GRAND HAVEN
43°00'
Grand
R.
SAUGATUCK
Kalamazoo
R.
SOUTH
HAVEN
BENTON HARBOR
St. Joseph
R.
42°00'
MICHIGAN
INDIANA
MICHIGAN CITY
R.
86°00'
Little
Cal
R.
GARY
88°00'
87°00'
LEGEND

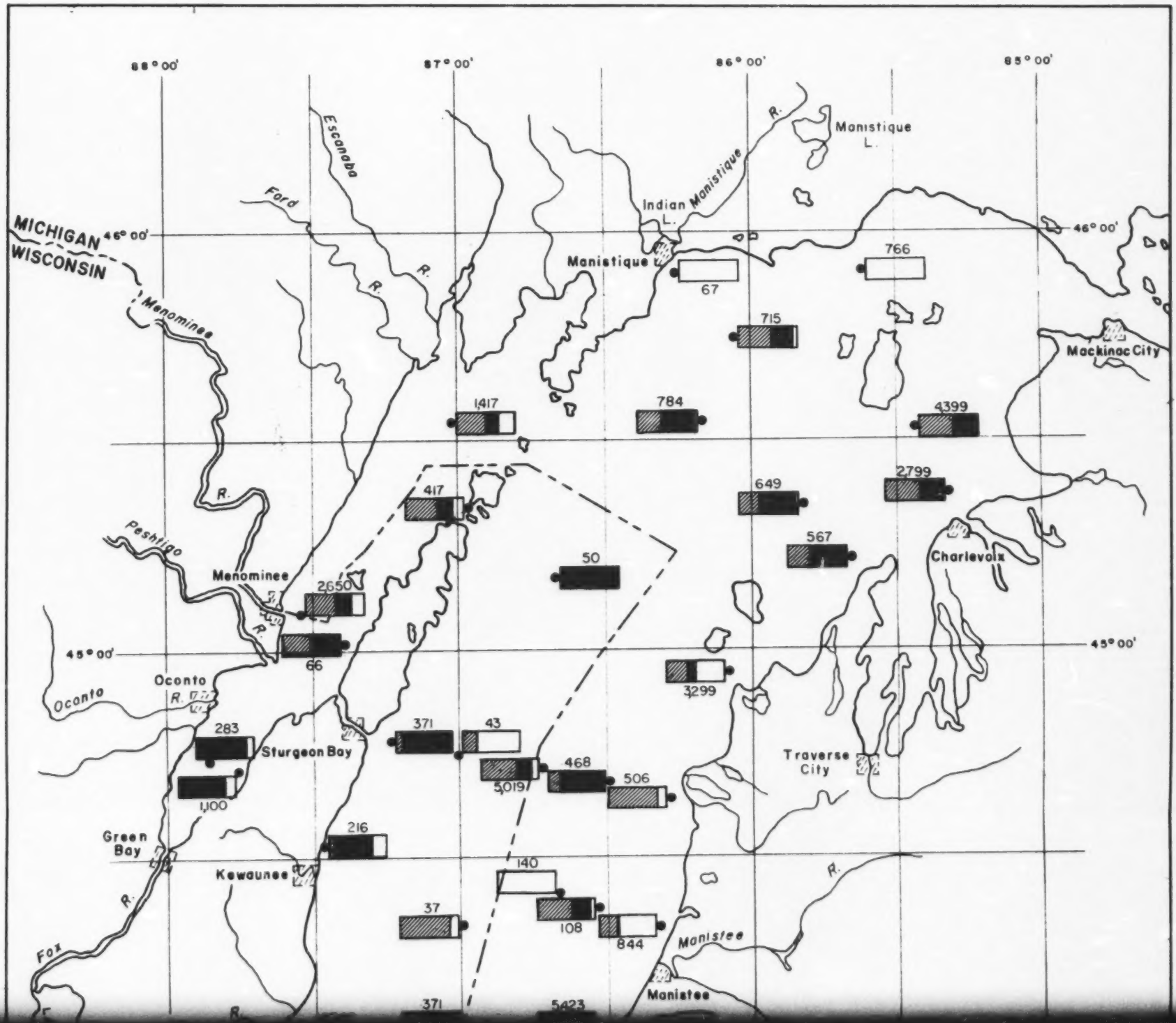


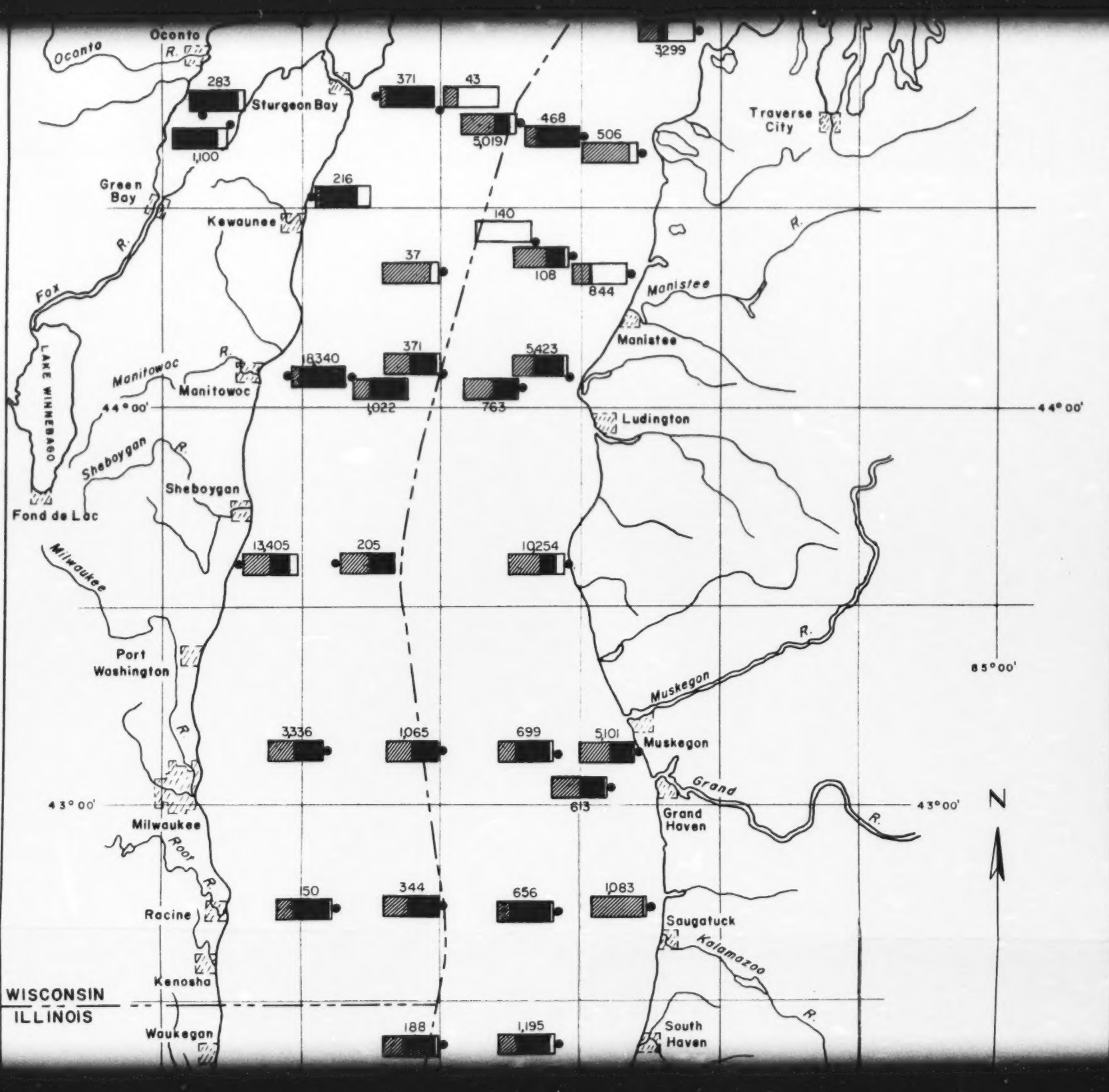
GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

LAKE MICHIGAN
TOTAL PHYTOPLANKTON COUNTS PER ML.
CR.7&8 OCTOBER 28-DECEMBER 4,1962

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 7


88° 00'
87° 00'
86° 00'
85° 00'
46° 00'
45° 00'
MICHIGAN
WISCONSIN
Escanaba R.
Ford R.
Menominee R.
Peshtigo R.
Oconto R.
Fox R.
Indian Manistique R.
Manistique L.
Manistique
Menominee
Oconto
Sturgeon Bay
Green Bay
Kewaunee
Mackinac City
Charlevoix
Traverse City
Manistee
67
766
715
1,417
784
4399
417
649
2799
567
50
2650
66
3299
283
1,100
371
43
5,019
468
506
216
140
108
844
37
371
5423


Oconto
Oconto R.
283
Sturgeon Bay
1,100
371
43
5,019
468
506
3299
Traverse City
Green Bay
216
Kewaunee
Fox R.
140
108
844
37
Manistee R.
Manistee
LAKE WINNEBAGO
Manitowoc R.
Manitowoc
18340
371
1,022
5423
763
44° 00'
Ludington
Sheboygan R.
Sheboygan
Fond de Lac
13,405
205
10254
Milwaukee R.
Port Washington
Muskegon R.
85° 00'
3336
1065
699
5101
613
Muskegon
Grand R.
43° 00'
Grand Haven
Milwaukee
Root R.
150
344
656
1083
Racine
Saugatuck
Kalamazoo R.
Kenosha
WISCONSIN
ILLINOIS
188
1,195
Waukegan
South Haven
N

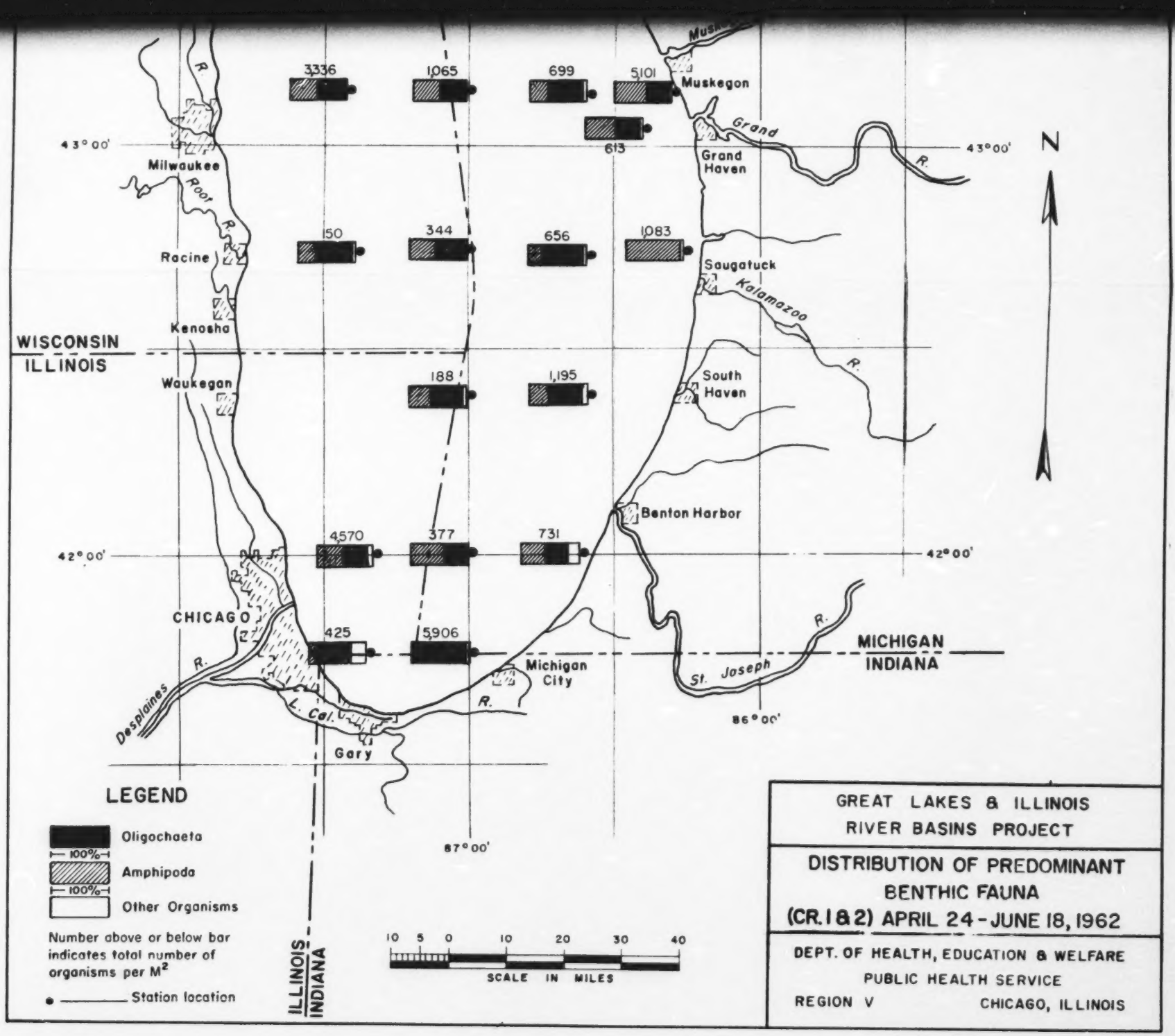
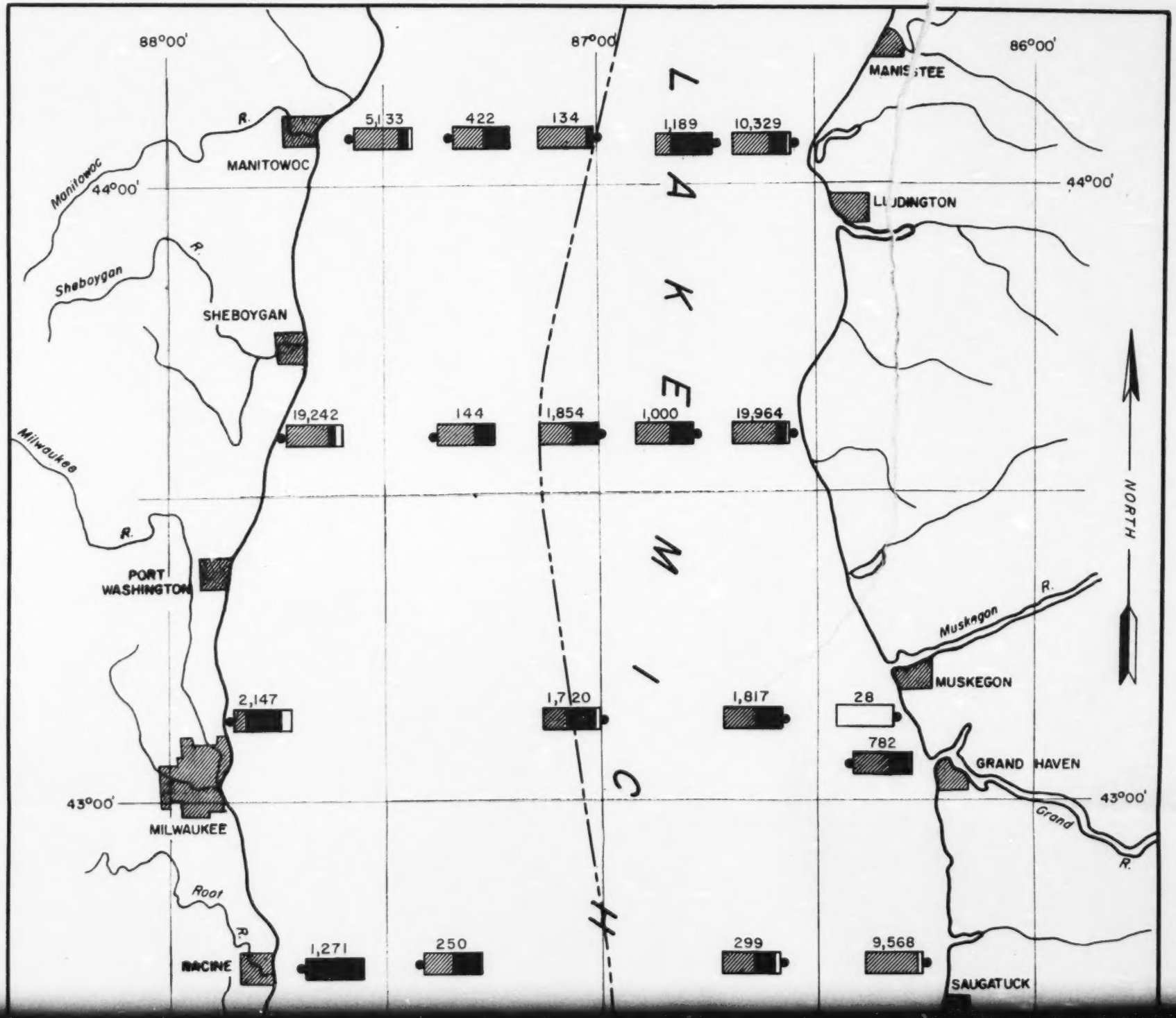
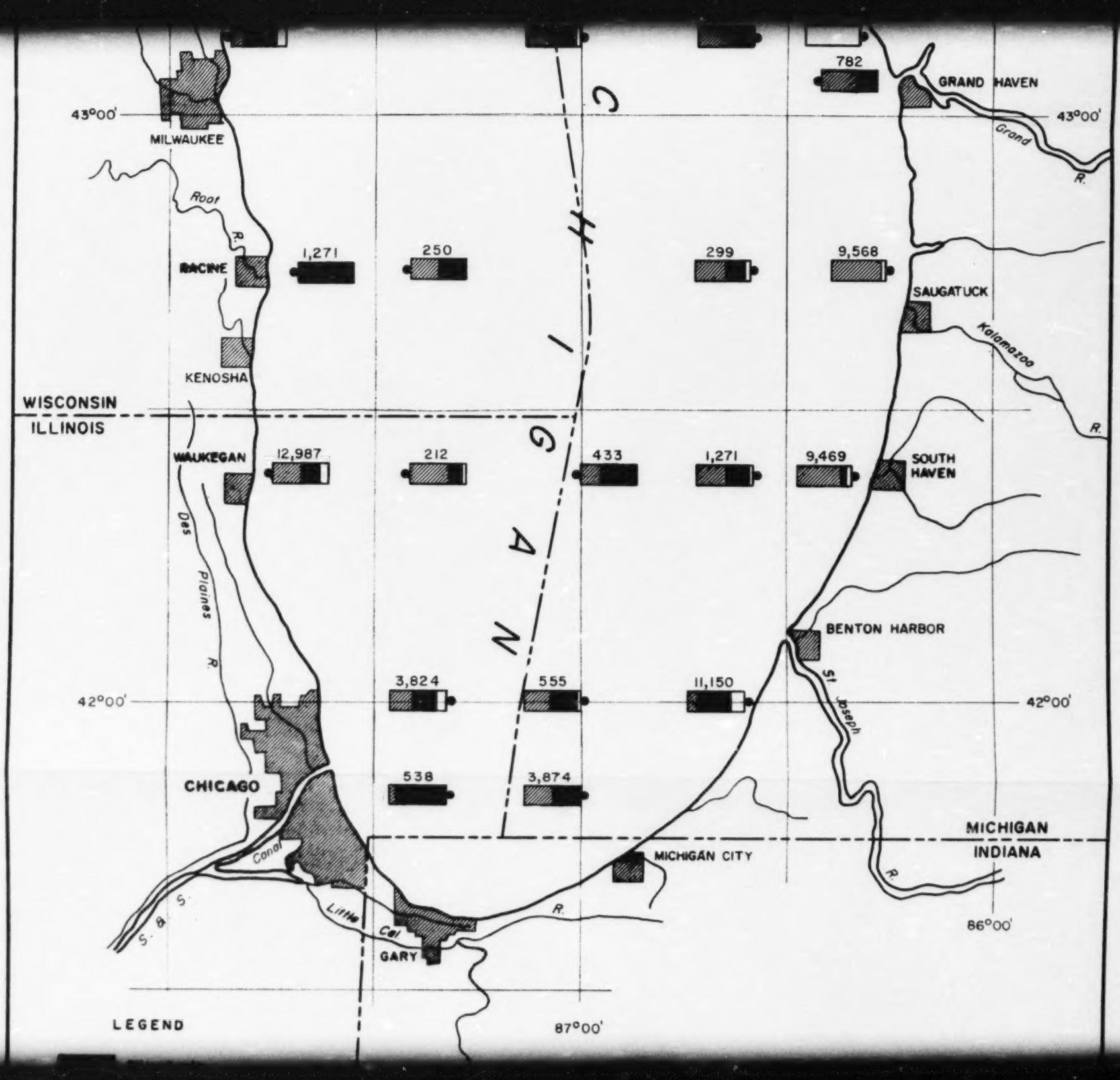
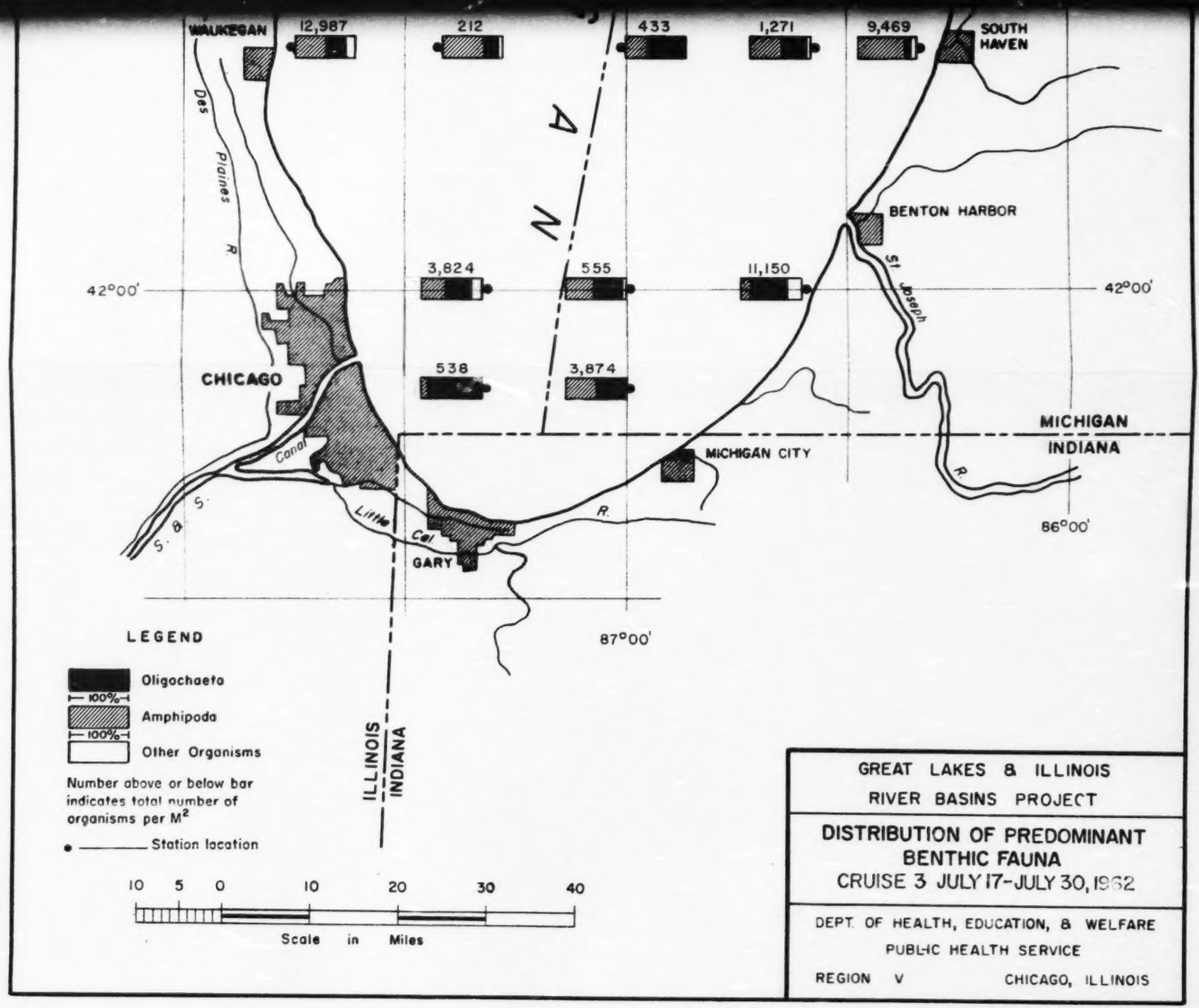

3,336
1,065
699
5,101
613
Muskegon
Grand
Grand Haven
R.
43°00'
N
Milwaukee
Racine
Kenosha
150
344
656
1,083
Saugatuck
Kalamazoo
R.
WISCONSIN
ILLINOIS
Waukegan
188
1,195
South Haven
Benton Harbor
4,570
377
731
42°00'
CHICAGO
425
5,906
MICHIGAN
INDIANA
Michigan City
St. Joseph
R.
Des plaines
R.
L. Cal.
Gary
86°00'
87°00'
LEGEND
Oligochaeta
100%
Amphipoda
100%
Other Organisms
Number above or below bar indicates total number of organisms per M²
Station location
ILLINOIS
INDIANA
10 5 0 10 20 30 40
SCALE IN MILES
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
DISTRIBUTION OF PREDOMINANT
BENTHIC FAUNA
(CR.1&2) APRIL 24 - JUNE 18, 1962
DEPT. OF HEALTH, EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION V
CHICAGO, ILLINOIS

FIGURE 8


88°00'
87°00'
86°00'
44°00'
43°00'
LAKE MICHIGAN
MANISTEE
MANITOWOC
LUDINGTON
SHEBOYGAN
PORT WASHINGTON
MUSKEGON
GRAND HAVEN
MILWAUKEE
RACINE
SAUGATUCK
Manitowoc R.
Sheboygan R.
Milwaukee R.
Root R.
Muskegon R.
Grand R.
NORTH
5,133
422
134
1,189
10,329
19,242
144
1,854
1,000
19,964
2,147
1,720
1,817
28
782
1,271
250
299
9,568


MILWAUKEE
Root R.
RACINE
KENOSHA
WISCONSIN
ILLINOIS
WAUKEGAN
Des Plaines R.
CHICAGO
Canal
S. B. S.
Little Cal R.
GARY
MICHIGAN CITY
MICHIGAN
INDIANA
BENTON HARBOR
St. Joseph R.
SAUGATUCK
Kalamazoo R.
GRAND HAVEN
Grand R.
43°00'
42°00'
86°00'
87°00'
LEGEND
1,271
250
299
782
9,568
12,987
212
433
1,271
9,469
3,824
555
11,150
538
3,874



GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

DISTRIBUTION OF PREDOMINANT BENTHIC FAUNA
CRUISE 3 JULY 17-JULY 30, 1962

DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 9